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Study and analysis of feeds and fertilizers for sustainable aquaculture development

Cover photographs:
Left top to bottom: Automatic silo feeders used in the intensive culture of tilapia in concrete tanks in Malaysia (courtesy of INFOFISH-Tarlochan Singh). Feeding semi-moist, farm-made feed to pangasiid catfish in ponds, Viet Nam (courtesy of L.T. Thanh Truc). Manual feeding of cultured fish at Barsiq Fish Farm, Behaira, Egypt (courtesy of Abdel-Fattah M. El-Sayed).
Right: Harvest of Indian major (catla, rohu and mrigal) and exotic (silver, grass and common) carps from a polyculture pond, Punjab, India (courtesy of Abhijit Paul).

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Edited by
Mohammad R. Hasan
Aquaculture Management and Conservation Service
Fisheries and Aquaculture Management Division
FAO Fisheries and Aquaculture Department
Rome, Italy

Thomas Hecht
Rhodes University
Grahamstown, South Africa

Sena S. De Silva
Network of Aquaculture Centres in Asia-Pacific
Bangkok, Thailand

and

Albert G.J. Tacon
FAO Consultant
Hawaii, United States of America

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Preparation of this document

This document was prepared by a group of experts under the leadership of Dr Mohammad R. Hasan as part of the FAO Aquaculture Management and Conservation Service's (FIMA) on-going programme entity "Monitoring, Management and Conservation of Resources for Aquaculture Development". A number of country reviews and case studies from Asia, Africa and a regional review for Latin America were commissioned to provide an overview of aquaculture and an analysis of feed and fertilizer use for the sustainable development of the sector. To reflect the diversity of aquaculture systems and practices in these regions seven countries were selected from Asia (Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam), six from Latin America (Brazil, Chile, Cuba, Ecuador, Mexico and the Bolivarian Republic of Venezuela) and eight from Africa (Cameroon, Egypt, Ghana, Kenya, Malawi, Nigeria, Uganda and Zambia). The country reviews for Asia and sub-Saharan Africa were synthesized, and a global synthesis was prepared on the basis of the three regional reviews (Asia, Latin America and sub-Saharan Africa). In addition and as part of the FIMA work programme, a targeted workshop on "Use of feeds and fertilizers for sustainable aquaculture development" was held in Wuxi, Jiangsu Province, China, on 18-21 March 2006. The workshop was organized by FIMA of FAO in collaboration with the Freshwater Fisheries Research Centre (FFRC) of China and the Network of Aquaculture Centres in Asia-Pacific (NACA).

Eight Asian and six African country reviews, a case study from Viet Nam, the three regional reviews and the global synthesis and the report of the workshop are included in this document. The report and recommendations of the workshop were circulated among the participants of the workshop and FAO FIMA technical officers for comment and the final report is incorporated in this technical paper.

The manuscripts in this technical paper were reviewed and technically edited by an editorial team led by Dr Mohammad R. Hasan. With a few exceptions, most of the reports included in the document were reviewed and edited in early 2007 before the FAO FishStat data for 2005 was released and hence data contained in most of the reports are for 2004. Updated aquaculture data for 2005 are available on FishStat (2007) (www.fao.org/fi/statist/FISOFT/FISHPLUS.asp). For consistency and conformity, scientific and English common names of fish species were used from FishBase (http://www.fishbase.org/home.htm). Most of the photographs in the country reviews and in the regional syntheses were provided by the authors. Where this is not the case, due acknowledgements are made to the contributors.

Much gratitude is due to the review and case study authors, who faced an enormous task and showed equally enormous patience with the editors. We acknowledge Ms Helen Nakouzi, Ms Hasini Wijesuriya, Ms Elena Irde and Ms Marika Panzironi for their assistance in word processing, Ms Tina Farmer, Ms Francoise Schatto and Ms Chrissi Smith-Redfern for their assistance in quality control and FAO house style and Mr José Luis Castilla Civit for layout design. The publishing and distribution of the document were undertaken by FAO, Rome.

Finally, Mr Jiansan Jia, Service Chief and Dr Rohana P. Subasinghe, Senior Fishery Resources Officer (Aquaculture), FAO Aquaculture Management and Conservation Service are gratefully acknowledged for providing the means, technical advice and moral support to initiate the study and to complete the publication.

Abstract

This compendium provides a comprehensive overview of feed and fertilizer use for sustainable aquaculture development in developing countries. It comprises of a series of review papers, including eight country reviews from Asia (Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam), six country reviews from Africa (Cameroon, Egypt, Kenya, Malawi, Nigeria and Uganda), one case study report from Asia, three regional reviews (Asia, Latin America and sub-Saharan Africa), a global synthesis as well as the final report of the FAO Expert Workshop on "Use of feeds and fertilizers for sustainable aquaculture development", held in Wuxi, Jiangsu Province, China, on 18-21 March 2006.

The country reviews provide an overview of the current status of aquaculture, a synthesis of the availability, accessibility and use of feed and fertilizer resources in relation to the diversity of farming systems and practices and an analysis of the nutritional, economic and social constraints of using these inputs. The regional reviews provide a synthesis of the country reviews by considering production trends and feed and fertilizer use from a wider geographic perspective and also analysed the projected expansion of the aquaculture sector in relation to the future availability of input commodities. The global synthesis provides a general overview and summarizes the future challenges facing the sector with respect to the use of feeds and fertilizers. The reviews as well as the case study reports provided the background information for the working group sessions of the workshop.

The working groups focused on the important role of farm-made aquafeeds in Asia and the need to develop and promote the use of farm-made feeds in sub-Saharan Africa, considered issues pertaining to the production and safe use of aquafeeds and deliberated on the constraints faced by industrial and small-scale aquafeed producers. Several key issues and constraints were identified, categorized and prioritized and appropriate actions were recommended. The workshop recommended that FAO undertake the following actions to assist regional organizations and member country governments to address the following identified issues and constraints on a regional and global perspective:

- review existing national standards and legislation regarding nutrient specifications (where these exist) for the manufacture of industrial and farm-made aquafeeds, and to provide guidelines and advisory material for different farming systems, practices and feed types;
- review existing national incentive mechanisms, subsidies and taxes affecting the animal feed manufacturing sector and feed ingredient usage, including feed commodity imports and exports and developing domestic promotion strategies;
- compile synopses of the nutritional requirements of major cultured fish species and the feed ingredients currently used in compound/farm-made aquafeeds, including national/regional feed ingredient source books containing information on nutrient composition, quality control criteria, seasonal availability and market price;
- encourage the strengthening of national/regional dialogue, exchange of information and assist with the setting of research priorities between researchers, the public sector and the aquaculture sector (including farmers and feed manufacturers), by supporting the activities of national/regional organizations, implementation of joint research projects, establishment of national farmer/aquafeed associations, and the development of web-based information and research networks; and

- strengthen capacity of farmers, feed manufacturers, private service providers, researchers and extension workers in aquaculture nutrition and feed technology, including on-farm feed management in developing countries (particularly in sub-Saharan Africa), and promote interregional cooperation.

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Contents

Contributors

S. Ahamad Ali, Central Institute of Brackishwater Aquaculture, 75, Santhome High Road, RA Puarm, Chennai 600 028, India. E-mail: Ali_madras@yahoo.com

Olajide A. Ayinla, Nigerian Institute for Oceanography and Marine Research, Victoria Island, P.M.B 12729, Lagos, Nigeria. E- mail: jideayinla@yahoo.com

S. Ayyappan, Indian Council of Agricultural Research, Krishi Anusndhan Bhavan, Pusa, New Delhi 110 012, India. E-mail: ayyapans@yahoo.co.uk

Benoy K. Barman, WorldFish Center, Bangladesh and South Asia Office, House 22B, Road 7, Block F, Banani, Dhaka 1213, Bangladesh. E-mail: b.barman@cgiar.org

S.K. Chimatiro, Department of Fisheries, PO Box 593, Lilongwe, Malawi. E-mail: SloansC@Nepad.org

B.B. Chirwa, Department of Fisheries, PO Box 593, Lilongwe, Malawi. E-mail: SloansC@Nepad.org

Sena S. De Silva, Network of Aquaculture Centres in Asia-Pacific, Bangkok, PO Box 1040, Kasetsart Post Office, Bangkok, 10903, Thailand. E-mail: sena.desilva@enaca.org

Abdel-Fattah M. El-Sayed, Oceanography Department, Faculty of Science, Alexandria University, Alexandria, Egypt. E-mail: a_elsayed50@yahoo.com

A. Flores-Nava, Universidad Marista de Mérida, AP 151-CORDEMEX, Mérida, Yucatán, 97300, México. E-mail: aflores@marista.edu.mx

Mohammad R. Hasan, Aquaculture Management and Conservation Service, FAO Fisheries and Aquaculture Department, Viale delle Terme di Caracalla, 00153 Rome, Italy. E-mail: Mohammad.Hasan@fao.org

Thomas Hecht, Department of Ichthyology and Fisheries Science, Rhodes University, Grahamstown 6140, South Africa. E-mail: t.hecht@ru.ac.za

Le Thanh Hung, Faculty of Fisheries, Nong Lam University, Ho Chi Minh City, Viet Nam. E-mail: lthungts@yahoo.com.vn

Huynh Pham Viet Huy, Faculty of Fisheries, Nong Lam University, Ho Chi Minh City, Viet Nam. E-mail: hpviethuy@yahoo.com

Manjurul Karim, WorldFish Center, Bangladesh and South Asia Office, House 22B, Road 7, Block F, Banani, Dhaka 1213, Bangladesh. E-mail: mkarim@mail.com

L. Mengqing, Yellow Sea Fisheries Research Institute, PO Box 266071, 106 Nanjing Road, Qingdao, China. E-mail: liangmq@ysfri.ac.cn

Abidin Nur, Centre for Brackishwater Aquaculture Development, Jepara, Central Java, Indonesia. E-mail: abidinnur@hotmail.com

Beatrice Nyandat, Department of Fisheries, PO Box 58187, 00100 Nairobi, Kenya. E-mail: tieny30@yahoo.com

Victor Pouomogne, Institute of Agricultural Research for Development (IRAD), Fishculture and Inland Fisheries Research Station, PO Box 255 Foumban, Cameroon. E-mail: pouomognev@yahoo.fr

J. Rutaisire, Department of Wildlife and Animal Resources, Makerere University, Kampala, Uganda. E-mail: jusruta@yahoo.com

Neila S. Sumagaysay-Chavoso, University of the Philippines Aquaculture Society, Inc., College of Fisheries and Ocean Sciences, Miag-ao, Iloilo, Philippines. E-mail: neila_sc@yahoo.com.sg

A. Victor Suresh, Aqua Feeds: Formulation and Beyond, A3 Sanskriti Apartments, 17 & 18 Velachery Bypass Road, Velachery, Chennai 600 042, India. E-mail: victor@feedware.com

Albert G.J. Tacon, Aquatic Farms Ltd., 49-139 Kamehameha Hwy., Kaneohe, Hawaii 96744, United States of America. E-mail: AGJTACON@aol.com

S. Thongrod, Coastal Aquatic Feed Research Institute, 41/14 Moo 9, Bangphra Sub-district, Sriracha District, Chonburi Province 20110, Thailand.
E-mail: supisthongrod@yahoo.com

Luu Thi Thanh Truc, Faculty of Fisheries, Nong Lam University, Ho Chi Minh City, Viet Nam. E-mail: luutruc235@yahoo.com

M. Weimin, Freshwater Fisheries Research Centre, 9 East Shanshui Road, Binhu District, Wuxi 214081, China. E-mail: miaowm@ffrc.cn

Foreword

Aquaculture has shown significant growth over the last three decades and it is anticipated that global aquaculture production will continue to increase. Total global fish production in 2005 was 157.53 million tonnes, of which aquaculture contributed about 40.0 percent (FAO, 2007)[1]. The average annual growth rate (APR) of the aquaculture sector during the period 1990 and 2004 was 9.4 percent per year. Aquaculture has been the fastest growing food production sector in many countries of the world for the last two decades, while capture fisheries have experienced a declining trend. Aquaculture has therefore, contributed significantly to food security and poverty alleviation in different parts of the world in parallel with the development of profit-oriented entrepreneurship.

In intensive aquaculture feed accounts for 60-80 percent of operational cost, while in semi-intensive aquaculture systems feed and fertilizers account for about 40-60 percent of production costs. Feeds and fertilizers will continue to dominate aquaculture needs. The importance of feed in aquaculture is further emphasized by the fact that about 28.2 million tonnes (44.8 percent) of total global aquaculture production in 2005 was dependent on single dietary ingredients, farm-made aquafeeds and industrially manufactured aquafeeds (FAO, 2007). In 2006, approximately 25.4 million tonnes of compound aquafeed was produced (Gill, 2007)[2] and used mainly for the production of non-filter feeding carps, marine shrimp, salmon, marine finfish, tilapia, trout, catfish, freshwater crustaceans, milkfish and eels (Tacon, Hasan and Subasinghe, 2006)[3].

It is estimated that in 2006 the aquaculture sector consumed about 3.06 million tonnes (56.0 percent) of world fishmeal production and 0.78 million tonnes (87.0 percent) of total fish oil production (Tacon, 2007)[4], while aquaculture's share of global industrial feed output was only four percent (Gill, 2007). In addition to fishmeal and fish oil, low value fish or 'trash fish' is used in many parts of the world as a complete or supplementary feed for farmed fish, crustaceans and a few mollusc species. It is estimated that approximately 5 to 6 million tonnes of low value/trash fish is used as direct feed in aquaculture (Tacon Hasan and Subasinghe, 2006).

Considering the dependency of carnivorous finfish and shrimp aquaculture on finite marine resources, it is unlikely that this sector will show major expansion in the near future, unless significant breakthroughs are made on the efficient use of alternatives to fishmeal and fish oil. It is anticipated that the production of freshwater finfish and crustacean low on the food chain will be the major contributors to global aquaculture production in future. Much of the expansion is likely to take place in semi-intensive farming systems and feed and fertilizer availability and accessibility will be the major limiting factors to achieving regional and global production targets.

To address these issues the Aquaculture Management and Conservation Service (FIMA) of the FAO Fisheries and Aquaculture Department initiated a work programme

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1 FAO. 2007. FAO Fisheries Department, Fishery Information, Data and Statistics Unit. Fishstat Plus: Universal software for fishery statistical time series. Aquaculture production: quantities 1950–2005; Aquaculture production: values 1984–2005; Capture production: 1950–2005; Commodities production and trade: 1950–2005; Total production: 1970–2005, Vers. 2.30 (available at www.fao.org/fi/statist/FISOFT/FISHPLUS.asp

2 Gill, C., 2007. World feed panorama: bigger cities, more feed. Feed International, 28 (1): 5-9.

3 Tacon, A.G.J., Hasan, M.R. and Subasinghe, R.P., 2006. Use of fishery resources as feed inputs for aquaculture development: trends and policy implications. *FAO Fisheries Circular.* No. 1018. Rome, FAO. 99 pp.

4 Tacon, A.G.J., 2007. Meeting the Feed Supply Challenges. Paper presented FAO Globefish Global Trade Conference on Aquaculture, Qingdao, China, 29–31 May 2007.

entitled "Study and analysis of feeds and nutrients (including fertilizers) for sustainable aquaculture development". After reviewing the existing status of aquaculture in relation to feeds and fertilizers and based on the recommendations made by COFI Sub-committee on Aquaculture (Beijing, Peoples' Republic of China and Trondheim, Norway[5]), the following key issues were prioritized and undertaken: a) an analysis of the status and trends in aquaculture production (with particular reference to fish and crustacean species that are dependent on feeds) and b) analyses of issues, trends and challenges in feed and fertilizer resource use for sustainable aquaculture development in developing countries in Asia, Africa and Latin America. The work programme is executed by FIMA in close collaboration with the FAO regional and sub-regional offices and in consultation with Regional Organization (e.g. NACA), government Department of Fisheries, Universities and National Research Institutions of FAO member countries.

To broaden the horizon of the consultative process and to review and analyze critical issues related to the use of feeds and fertilizers for sustainable aquaculture development, a targeted workshop on "Use of feeds and fertilizers for sustainable aquaculture development" was organized in Wuxi, Jiangsu Province, China on 18-21 March 2006 in collaboration with the Freshwater Fisheries Research Centre (FFRC) of China and the Network of Aquaculture Centres in Asia-Pacific (NACA). The workshop combined technical presentations and working group discussions. A number of country reviews from Asia and Africa, case studies, three regional syntheses (Asia, Africa and Latin America) and a global synthesis were commissioned prior to the workshop and selected reviews, case studies, syntheses were presented at the workshop. The workshop brought together 21 experts in the field of aquaculture nutrition and aquafeeds, including the authors of the country reviews, case studies, regional and global syntheses and experts from FAO, FFRC and NACA. The workshop identified several key issues and constraints in relation to the use of feeds and fertilizers for sustainable aquaculture development and recommended appropriate actions to address these issues and constraints.

This technical paper presents the report of the workshop, a summary of the working group discussions and the recommendations made by the workshop, the country reviews, case study reports as well as the regional and global syntheses. It is anticipated that the identified key issues and recommendations will assist policy makers on a regional and global level to promote improved aquaculture practices and farming systems through optimal use of feed and fertilizer resources and that this will help FAO member countries to implement the provisions of the Code of Conduct for Responsible Fisheries.

Jiansan Jia
Chief
Aquaculture Management and Conservation Service
FAO Fisheries and Aquaculture Department

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[5] FAO, 2003. Report of the Second Session of the Sub-Committee on Aquaculture. Trondheim, Norway, 7–11 August 2003. *FAO Fisheries Report.* No. 716. Rome, FAO. 91 pp.

Executive summary

For the last two decades aquaculture has been the fastest growing food production sector in many countries of the world and has contributed significantly to food security and poverty alleviation in different parts of the world in parallel with the development of profit-oriented entrepreneurship. The global average annual growth rate of the sector during the period 1990 and 2004 was 9.4 percent per year, while capture fisheries have experienced a declining trend.

Aquaculture in Asia, Latin America and Africa is growing rapidly and this presents significant growth opportunities for the aquafeed sector. Except for salmon in Chile, warm- freshwater, omnivorous fish contribute the bulk of aquaculture production in these regions. There are notable differences among the three continents in terms of production and the use of aquafeeds and each region has its own set of priorities for developing the aquafeed sector. In Asia, farm-made aquafeeds play a dominant role in fish production, although intensification of farming practices is driving the growth of the industrial aquafeed sector. In Latin America, industrial aquafeeds are widely used in most production systems. In sub-Saharan Africa, where aquaculture production is small, but actively growing, on-farm feed manufacturing by small- and medium-scale entrepreneurs is beginning to play an important role in aquaculture development. Understanding these differences and setting of priorities are critical to the future development of the aquafeed sector, particularly in the tropics.

Asia accounted for 92.1 percent of global aquaculture production in 2005 (57.97 million tonnes), to which China contributed 74.6 percent. Nine other countries contributed 22.7 percent. Aquaculture in Asia is primarily rural and pond-based semi-intensive farming of species low on the food chain, with the exception of shrimp and some freshwater and marine carnivorous species. Farm-made feeds are used throughout the region primarily for semi-intensive farming while nutritionally-complete, industrially manufactured feeds are used for intensive farming of high-value species.

In the seven major Asian aquaculture producing countries (China, India, Indonesia, the Philippines, Viet Nam, Thailand and Bangladesh) an estimated 19.33 million tonnes of farm-made feed and 10.30 million tonnes of industrial aquafeeds were used in 2003-04. It is predicted that feed usage over the next five years will increase to 30.73 million tonnes and 22.24 million tonnes for farm-made and industrial aquafeeds, respectively, representing a growth of 60 and 107 percent from current levels. The current and continuing importance of farm-made feeds in Asian aquaculture calls for increased efficiency in the production and use of farm-made feeds.

Increased production of high-value aquatic species and intensification of existing culture practices of freshwater finfish, has contributed significantly to the increased production and utilization of industrial aquafeed in the region. To sustain the predicted increase in the use of aquafeeds requires a concerted regional research and development initiative, improvements in production technology and feeding practices. In particular these initiatives should focus on the use of fishmeal and soybean meal. It is pertinent to note that the demand and use of fishmeal in some of the emerging aquaculture countries in Asia is increasing rapidly. For example, Viet Nam already uses approximately 62 500 tonnes of fishmeal per year, solely for aquaculture. Further, in 2004 China alone imported an estimated 20.2 million tonnes of soybean, accounting for over one third of world soybean imports. Intensification of aquaculture in Asia is likely to further increase fishmeal usage with China being a decisive factor with respect to supply and demand. The search for suitable and cost-effective alternative protein sources for use in industrial aquafeeds will be the most critical factor in the development of intensive aquaculture in Asia.

Aquaculture in Latin America is dominated by Chile and Brazil (50.9 percent and 18.4 percent of Latin American production in 2005). The balance (30.7 percent) was produced by 30 other countries. On the species-group level, salmonids (primarily Altantic salmon, *Salmo salar*), shrimp (Pacific white shrimp, *Litopenaeus vannamei*), and tilapia accounted for about 77 percent of regional aquaculture production. Freshwater aquaculture species includes tilapia (*Oreochromis* spp.), catfish, carps (common and Chinese carps), rainbow trout and a number of native species, such as tambaqui (*Colossoma macropomum*), and pacú (*Piaractus mesopotanicus*). Of these species, tilapia shows the highest growth rate in production with an annual average increase of 15.7 percent between 1999 and 2002 followed by other species such as tambaquí, and Pacú. The industry in the region is generally well developed, with production almost exclusively realized through semi-intensive and intensive farming systems.

Industrially manufactured feeds are readily available in most countries. Large feed manufacturers in Chile, Brazil, Mexico, Costa Rica and Colombia produce salmon, shrimp, tilapia and trout feeds. Farm-made feeds are rarely used in the region except in localized areas in selected countries where a small number of small-scale farmers occasionally utilize some agricultural by-products to replace or complement formulated complete diets. Opportunities to integrate aquaculture into the traditional agricultural systems by small-scale farmers is constrained by the high cost of formulated feeds, and the lack of knowledge on the use of locally available ingredients to produce low cost, farm-made aquafeeds.

The aquafeed industry in Latin America is largely dependent on conventional sources of protein and fishmeal and fish oil continue to be the core dietary protein and lipid sources, respectively. Other major protein sources include a number of ingredients such as soybean meal, maize gluten meal and rendered animal byproducts. A wide range of other agri-industrial by-products and other potential nutrient sources are readily available in countries like Brazil, Ecuador and Mexico, but their use in aquafeeds is constrained by limited research.

Total production in Africa in 2005 was estimated to be 656 370 tonnes, to which Egypt alone contributed about 82.2 percent. Sub-Saharan Africa accounted for 16.8 percent of the total African production. Aquaculture in sub-Saharan Africa (SSA) is dominated by Nigeria contributing about 51.5 percent, while the other nine top producers contributed about 41.0 percent of SSA production. Between 1999 and 2005, overall production in SSA increased by 99 percent from 54 997 tonnes to 109 446 tonnes. However, aquaculture in SSA is widely dichotomous: more than 70 percent of the regional total production is produced on commercial farms by less than 20 percent of farmers, while less than 30 percent is produced by small-scale subsistence farmers that comprise over 80 percent of all farmers. The systems used by the commercial sector range from semi-intensive to intensive pond, cage and tank culture of catfish (*Clarias* spp.) and tilapia (*Oreochromis* spp.) and high-value products such as shrimp (Madagascar and Mozambique) and abalone (South Africa) while non-commercial subsistence aquaculture primarily consists of small-scale pond culture of tilapia, catfish and common carp (*Cyprinus carpio*).

Large-scale commercial aquaculture is primarily dependent on industrially manufactured feeds. The feeds are either produced within country or imported. In most SSA countries, conventional aquafeed formulations rely heavily on imported fishmeal to provide much of the dietary protein. The price of fishmeal coupled with high import tariffs and taxes in most countries will affect the development of the aquafeed industry in and the development of the sector in the region as a whole. The situation therefore warrants careful evaluation of alternative, locally available protein sources of animal origin, as well as greater and improved use of agricultural by-products in aquafeed formulations.

Farm-made feeds are manufactured by individual farmers as well as small and medium-scale entrepreneurs. In some countries this is a rapidly emerging manufacturing sector and the technologies employed by these entrepreneurs are simple and the feed is generally affordable but has a limited shelf life. Country reviews of seven selected countries (Cameroon, Ghana, Kenya, Malawi, Nigeria, Uganda and Zambia) of SSA revealed that approximately 12 000 tonnes of industrial feeds were produced in 2005 contributing to a maximum of 15.6 percent of total fish production, while the production of farm-made aquafeeds produced by medium- and small-scale entrepreneurs as well as by farmers during the same period was 98 500 tonnes. The growth of the small-scale sector in the region is constrained principally by an inadequate knowledge base on the use of farm-made feeds. In addition, small-scale farmers are constrained by the availability of animal manure because of the free range nature of animal husbandry, and the cost of inorganic fertilizers. There is not much that can be done about the latter and hence there is a need to focus on farm-made feeds.

Already there is a substantial body of regional knowledge of the allowable inclusion levels for many locally available and on-farm feed ingredients but little has been done to evaluate these data with respect to farm economics and to translate the findings into practice. Further, information on appropriate feed mixes and preparation techniques for farm-made aquafeed, subregional databanks on seasonal availability of agricultural commodities and a suitable mechanism to disseminate this information are lacking. These needs must be addressed if the region is to realize its potential and production capacity. A greater degree of regional cooperation between Asia and Africa has been identified as one of the mechanisms to address these needs.

There are several pivotal issues related to feed and fertilizers that the aquaculture industry in Asia, sub-Saharan Africa and Latin America will have to address in the next few years. These are:

- reduced accessibility resulting from increasing costs of fishmeal and other conventional protein sources;
- tougher environmental protection measures, and stringent food safety requirements and quality standard imposed by local governments, regional and international agreements, consumer groups and importers;
- mono- and oligopoly of feed industries resulting in regionalization of markets, reduction of local competition and consequently restricting types, and quality of products, particularly in Latin American countries;
- assurance of national quality standards for raw materials, feed additives and feeds;
- safe and appropriate use of aquafeeds produced by small-scale manufacturers and support to improve their production technology; and
- development of on-farm feeding strategies and practices for improved utilization of agricultural and terrestrial by-products and capacity building of small-scale farmers to make more effective farm-made feeds.

These issues will have a profound impact on the future development of the aquaculture sector on the three continents and must be addressed if sustainable development is to be ensured.

Abbreviations and acronyms

AARM	Aquaculture and Aquatic Resources Programme, AIT, Thailand
ADB	Asian Development Bank
ADiM	Aquaculture Development in Malawi
AFMA	Animal Feed Manufacturing Association of South Africa
AFSD-BAI	Animal Feed Standard Division-Bureau of Animal Industry (Philippines)
AIFP	Aquaculture and Inland Fisheries Project (Nigeria)
AIT	Asian Institute of Technology
APR	Average Percent growth Rate
ASA	American Soybean Association
ASEAN	Association of Southeast Asian Nations
BAI	Bureau of Animal Industry (Philippines)
BAS	Bureau of Agricultural Research (Philippines)
BBS	Bangladesh Bureau of Statistics
BCA	Bangladesh Census for Agriculture
BDT	Bangladesh Taka (currency)
BFAR	Bureau of Fisheries and Aquatic Resources (Philippines)
BFDC	Bangladesh Fisheries Development Corporation
BFRI	Bangladesh Fisheries Research Institute
BFS	Balance Fertilization Strategy
BRAC	Bangladesh Rural Advancement Committee
BSE	Bovine Spongiform Encephalopathy
CAPMS	Central Agency for Public Mobilisation and Statistics, Egypt
CAR	Cordillera Administrative Region (Philippines)
CBAD	Centre for Brackishwater Aquaculture Development (Indonesia)
CEPID	Centre d'Excellence pour la Production, l'Innovation et le Développement
CEPT	Common Effective Preferential Tariff
CLFMA	Compound Livestock Feed Manufacturers Association, India
CoC	Code of Conduct
CP	Charoen Pokphand Foods Co. Ltd., Thailand
DA	Department of Agriculture (Philippines)
DAE	Department of Agricultural Extension, Ministry of Agriculture, Bangladesh
DAP	Di-Ammonium Phosphate
DFID	Department for International Development (UK)
DoF	Department of Fisheries
DOST	Department of Science and Technology (Philippines)
DTI	Department of Trade and Industry (Philippines)
EEZ	Exclusive Economic Zone
FADINAP	Fertilizer Advisory, Development and Information Network for Asia and the Pacific
FCR	Feed Conversion Ratio
FEWS	Famine Early Warning System
FIAP	Fertilizer Industry Association of the Philippines
FISH	Fisheries Investment for Sustainable Harvest

FMB-DENR	Forest Management Bureau-Department of Environment and Natural Resources (Philippines)
FPA	Fertilizer and Pesticide Authority (Philippines)
FSR	Fisheries Sector Review, Bangladesh
GAFRD	General Authority for Fisheries Resources Development, Egypt
GAMP	General Authority of Milling and Polishing, Egypt
GAP	Good Aquaculture Practice
GDP	Gross Domestic Product
GIFT	Genetically Improved Farmed Tilapia
GI-Macro	Genetic Improvement of *Macrobrachium*
GNAEP	Greater Noakhali Aquaculture Extension Project, Bangladesh
ha	hectare
HACCP	Hazard Analysis Critical Control Point
HPAI	Highly Pathogenic Avian Influenza
HUFA	Highly Unsaturated Fatty Acid
IDRC	International Development Research Centre, Canada
IFFN	Innovative Fish Farmers Network, Malawi
IITA	International Institute of Tropical Agriculture
INCHEM	International Chemical Corporation
IRAD	Institue of Agricultural Research for Development, Cameroon
JICA	Jambi Initiative for Commercial Aquaculture
JICA	Japan International Cooperation Agency
LASADA	Lagos State Agricultural Development Agency (Nigeria)
LE	Egyptian Pound, LE (Egypt Pound, EGP)
LGU	Local Government Unit
LLDA	Laguna Lake Development Authority (Philippines)
MAAIF	Ministry of Agriculture, Animal Industries and Fisheries, Uganda
MBD	Microbound Diet
MBS	Malawi Bureau of Standards
MFN	Most Favoured Nations
MINEPIA	Ministère de l'Elevage, des Pêches et des Industries Animales, Cameroon
MOFL	Ministry of Fisheries and Livestock, Bangladesh
MPEDA	Marine Products Export Development Authority, India
NAC	National Aquaculture Centre of the Department of Fisheries, Malawi
NAMRIA	National Mapping and Resource Information Authority (Philippines)
NARO	National Agricultural Research Organization, Uganda
NASO	National Aquaculture Sector Overview, FAO
NCR	National Capital Region
NEDA	National Economic Development Authority (Philippines)
NFA	National Food Authority (Philippines)
NGO	Non Governmental Organization
NIFFR	National Institute for Freshwater Research, Nigeria
NIOMR	Nigerian Institute for Oceanography and Marine Research, Nigeria
NMIS	National Meat Inspection Service (Philippines)
NPK	Nitrogen Phosphate Potassium
NPKS	Mixed fertilizer containing nitrogen, phosphorus, potassium and sulfur
NSO	National Statistics Office (Philippines)
NSPFS	National Special Programme for Food Security (Nigeria)
PABEP	Potuakhali and Barguna Aquaculture Extension Project, Bangladesh
PCA	Philippine Coconut Authority

PCV	Peace Corps Volunteer (USA)
PL	Post Larvae
PMA	Plan for Modernization of Agriculture
PNVRA	Programme National de Recherche et de Vulgarisation Agricole, Cameroon
ppm	parts per million
ppt	part per thousand
QUEDANCOR	Quedan Rural Credit and Guarantee Corporation (Philippines)
RA	Republic Act
Rs	Indian Rupee (INR)
SEAFDEC	Southeast Asian Fisheries Development Center
SEAPB	Service d'Appui aux Populations à la Base, Cameroon
SIFAB	Société Industrielle de Fabrication des Aliments pour le Bétail, Cameroon
SIFAC	Syndicat de la Filière Avicole au Cameroun
SPF	Specific Pathogen Free
SSA	Sub-Saharan Africa
SSP	Single Super Phosphate
TSP	Triple Super Phosphate
UNDP	United Nations Development Programme of the United Nations
USAID	United States Agency for International Development
USGC	United States Grain Council
USh	Uganda Shilling
WFP	World Food Programme of the United Nations
WSSV	White Spot Syndrome Virus

GLOBAL SYNTHESIS AND REGIONAL REVIEWS

Global synthesis of feeds and nutrients for sustainable aquaculture development

Albert G.J. Tacon
Aquatic Farms Ltd
49-139 Kamehameha Hwy., Kaneohe, Hawaii 96744
United States of America
Mohammad R. Hasan
Aquaculture Management and Conservation Service
FAO Fisheries and Aquaculture Department, Rome 00153
Italy

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SUMMARY

The aim of the study was to review status and trends concerning the use of aquaculture feeds and nutrients (including fertilizers) within selected developing countries within sub-Saharan Africa (Cameroon, Ghana, Kenya, Malawi, Nigeria, Uganda, Zambia), Latin America (Brazil, Chile, Cuba, Ecuador, Mexico, Bolivarian Republic of Venezuela) and Asia (Bangladesh, China, India, Indonesia, the Philippines, Thailand, Viet Nam). This synthesis paper is based on a review of the results and conclusions reached by the authors of the three regional review papers for Asia (De Silva and Hasan, 2007), Latin America (Flores-Nava, 2007) and sub-Saharan Africa (Hecht, 2007). In addition, the current paper also contains some personal observations and comments of the authors concerning feed and ingredient use within the target countries and globally.

The following general observations were made on the regional reviews, namely:

1. the absence of precise official statistical information concerning the percent of aquaculture production within most developing countries using industrially compounded aquafeeds, farm-made aquafeeds or whole food items (such as trash fish), either by major cultured species group or farming system;
2. the total estimated compound aquafeed production within the 20 selected countries (that collectively accounted for 86.3 percent of global aquaculture production by weight in 2003) was estimated to be just over 11.5 million tonnes (Latin America select – 1.2 million tonnes, sub-Sahara select – 12 000 tonnes and Asia select – 10.30 million tonnes;
3. with the possible exception of China and the selected Asian countries (where total farm-made aquafeed production was estimated at 19.3 million tonnes), the absence of information on total current production of farm-made aquafeeds in the selected sub-Saharan and Latin American countries;
4. the importance of farm-made aquafeeds within extensive and semi-intensive pond farming systems in Asia and sub-Saharan African countries, and in particular for the production of lower value freshwater fish species for home consumption;
5. with the possible exception of Brazil (in the case of freshwater fish species), the bulk of aquaculture species produced in the selected Latin American countries were higher value species destined for export to developed country markets, including salmonids (Chile) and marine shrimp (Brazil, Cuba, Ecuador, Mexico, Bolivarian Republic of Venezuela). A similar situation also existed in the selected Asian countries (with the exception of freshwater food-fish species), with the bulk of penaeid shrimp and marine finfish production destined for export; over 99 percent of global farmed shrimp production being produced in developing countries, primarily for export to developed country markets of North America, Europe and Japan;
6. the increasing national, regional and global competition for available feed and nutrient resources between the aquaculture sector and the animal livestock sector, including humans for direct food use and the need for the aquaculture sector to identify and utilize more sustainable feed and nutrient sources as feed inputs to maintain the growth and long term sustainability of the regional aquaculture sectors;
7. realisation that the bulk of small-scale farmers in sub-Saharan Africa and to a lesser extent within the selected Asian and Latin American countries do not have the financial resources to purchase feed and/or nutrient inputs for their aquaculture operations;
8. the increased dependence and use of fishmeal and fish oil (including lower value trash fish species) within feeds for higher value cultured species destined for exports;
9. although Latin American countries are currently self sufficient in fishmeal and fish oil supplies, the selected Asian and sub-Saharan countries are currently all net importers of fishmeal and/or fish oil;
10. the trend toward the development and use of more environmentally friendly feeds and feeding regimes, including the increasing development and use of highly digestible

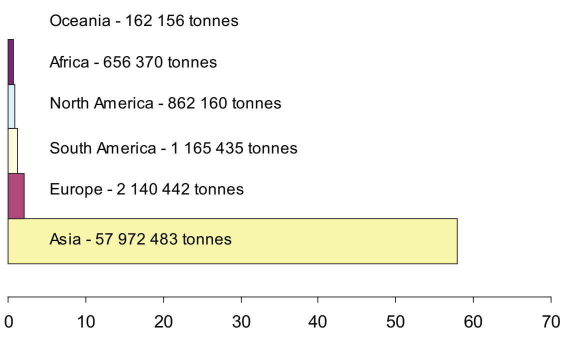
extruded aquafeeds by the commercial aquafeed sector, in particular within those countries where environmental degradation and water pollution are major/potential aquaculture development issues;

11. the trend within some regions, including the Latin American region, toward the consolidation of the commercial aquafeed manufacturing sector, which in some cases has resulted in regionalization of markets, thus reducing local competition and consequently restricting types, presentations and even quality of products;
12. the recognition of the important role played by national feed industry associations and government policy, to improve feed manufacturing, feed storage and quality control guidelines, import restrictions, duties, customs clearance procedures and incentives and by so doing facilitating the sustainable development of the resident aquafeed manufacturing sector and ensuring that the farmer receives a consistence quality product targeted to the dietary needs of the cultured species;
13. the lack of information and regulation concerning the presence of heavy metal and other environmental contaminants within aquafeeds (and consequently the cultured aquaculture product) and possible short and long term effects on human health, including possible export/import restrictions;
14. the lack of resident expertise and training opportunities in aquaculture nutrition and feed manufacturing technology within most sub-Saharan African countries, including feeds and feeding based development projects and undergraduate and postgraduate university training courses;
15. the lack of ready available practical information concerning the dietary nutrient requirements of the major fed aquaculture species, including up-to-date information concerning aquaculture nutrition, feed ingredient usage, feed formulation feed manufacture and on-farm feed management, including the development and use of appropriate on-farm research methods; and
16. the recognition of the global importance of China in the production of farmed aquatic produce, including importation of key feed ingredients and nutrients, and possible long terms effects on global fish supplies, fish prices and the long term global sustainability of the aquaculture sector.

1. INTRODUCTION

This paper presents a global overview of aquaculture feeds and feeding, with particular reference to the production and use of feeds and fertilizers by the rapidly growing aquaculture sector in Asia, sub-Saharan Africa and Latin America. Although this overview draws heavily upon the findings and conclusions of three regional review papers of De Silva and Hasan (2007) for Asia (country reviews: Bangladesh, China, India, Indonesia, the Philippines, Thailand, Viet Nam), Hecht (2007) for sub-Saharan Africa (country reviews: Cameroon, Ghana, Kenya, Malawi, Nigeria, Uganda, Zambia) and of Flores-Nava (2007) for Latin America (country reviews: Brazil, Chile, Cuba, Ecuador, Mexico, the Bolivarian Republic of Venezuela), other available information sources were also consulted where relevant.

FIGURE 1
Total aquaculture production by continent



2. GLOBAL OVERVIEW OF AQUACULTURE PRODUCTION AND FARMING SYSTEMS

In 2005, global aquaculture production reached 63.0 million tonnes, valued at US$78.4 billion (FAO, 2007). Moreover, the sector has been growing at an average compound rate (APR) of 9.2 percent per year since 1990, increasing over 3.7 fold from 16.83 million tonnes in 1990 to 63.0 million tonnes in 2005.

By continent, Asia is by far the largest producer of aquaculture products (Figure 1). In 2005 Asia produced 57.97 million tonnes or 92.1 percent of total global production by weight (80.5 percent by value), followed by Europe 2.14 million tonnes

TABLE 1
Summary of reported total aquaculture production in Asia in 2005

Country/species	Production (tonnes)	Value (US$ billion)
Total	**57 972 483**	**63.14**
Top 10 countries by production		
China	43 269 413	39.79
India	2 842 419	3.92
Indonesia	2 124 093	2.32
Philippines	1 895 848	0.90
Viet Nam	1 467 300	2.94
Japan	1 253 963	4.27
Thailand	1 144 011	1.69
Republic of Korea	1 057 386	1.45
Bangladesh	882 091	1.25
Democratic People’s Republic of Korea	507 995	0.30
Top finfish & crustacean species groups		
Freshwater fish	24 419 668	24.76
Crustaceans	3 644 151	14.26
Marine fish	1 305 507	4.23
Diadromous fish[1]	1 032 377	2.21
Top cultivated finfish & crustacean species		
Carps, barbels & other cyprinids	19 088 487	17.36
Miscellaneous freshwater fish[2]	3 741 385	5.78
Shrimp	2 376 161	9.19
Tilapia	1589 796	1.61
Freshwater crustaceans	998 598	4.35

[1] Includes salmonids, milkfish, eels and sturgeons;
[2] Includes catfishes, mandarin fish (in the case of China), snakehead and gourami, etc.
Source: FAO (2007)

(3.4 percent by weight), South America 1.16 million tonnes (1.85 percent), North America 0.86 million tonnes (1.37 percent), Africa 0.66 million tonnes (1.0 percent) and Oceania 0.14 million tonnes (0.26 percent) (FAO, 2007).

On the basis of the three geographic regions surveyed in this report, total aquaculture production by major producing country and by major cultivated finfish and crustacean species groups is summarized in Tables 1, 2 and 3.

TABLE 2

Summary of reported total aquaculture production in Latin America and the Caribbean in 2005

Country/species	Production (tonnes)	Value (US$ billion)
Total	**1 401 554**	**5.69**
Top 10 countries by production		
Chile	713 706	3.12
Brazil	257 783	0.91
Mexico	117 514	0.47
Ecuador	78 300	0.31
Colombia	60 072	0.28
Honduras	29 380	0.05
Peru	27 468	0.17
Costa Rica	24 038	0.08
Cuba	22 635	0.03
Bolivarian Republic of Venezuela	22 210	0.07
Top finfish & crustacean species groups		
Diadromous fish[1]	617 540	2.85
Freshwater fish	351 242	0.99
Crustaceans	279 303	1.27
Marine fish	8 521	0.12
Top cultivated finfish & crustacean species		
Salmonids	617 540	2.85
Shrimp	278 385	1.26
Tilapia	182 266	0.48
Miscellaneous freshwater fish[2]	92 260	0.32
Carps, barbels & other cyprinids	76 716	0.18

[1] Includes salmonids and sturgeons; [2]Includes catfishes, pacu and *Colossoma,* etc.

Source: FAO (2007)

TABLE 3

Summary of reported total aquaculture production in sub-Saharan Africa in 2005

Region/country/species	Production (tonnes)	Value (US$ billion)
Total	**109 466**	**0.296**
Top 10 countries by production		
Nigeria	56 355	0.159
Uganda	10 817	0.012
Madagascar	8 500	0.034
South Africa	6 142	0.036
Tanzania	6 011	0.001
Zambia	5 125	0.009
Congo	2 965	0.007
Zimbabwe	2 452	0.005
Togo	1 535	0.003
Mozambique	1 278	0.007
Top finfish & crustacean species groups		
Freshwater fish	88 831	0.213
Crustaceans	7 907	0.043
Diadromous fish	1 045	0.004
Marine fish	594	0.003
Top cultivated finfish & crustacean species		
Miscellaneous freshwater fish[1]	59 069	0.159
Tilapia	27 004	0.050
Shrimp	7 893	0.042

[1] Includes catfishes, snakeheads and African bonytongue, etc.

Source: FAO (2007)

Interestingly, despite the differences in size between the three target regions, the growth of the aquaculture sector within each region has been remarkably similar; total production in Asia increasing 4.0 fold from 14.50 million tonnes in 1990 to 57.97 million tonnes in 2005 at an average APR of 9.7 percent, total production in Latin America and the Caribbean increasing 6.1 fold from 230 658 tonnes in 1990 to 1 401 554 tonnes in 2005 with an average APR of 12.8 percent, and in sub-Saharan Africa total production increasing 5.9 fold from 18 410 tonnes in 1990 to 109 466 tonnes in 2005 at an average APR of 12.6 percent (FAO, 2007).

Moreover, aquaculture production within each region is currently dominated by one country, namely China (43.27 million tonnes or 74.6 percent of total Asia production; Table 1), Chile (713 706 tonnes or 50.9 percent of total Latin America and Caribbean production; Table 2) and Nigeria (56 355 tonnes or 51.5 percent of total sub-Saharan Africa production; Table 3). However, the production of major fed species within these regions is quite different, ranging from mainly freshwater fish species and crustaceans in sub-Saharan Africa (includes catfishes and tilapia on the African mainland, and penaeid shrimp in Madagascar and the Seychelles), primarily freshwater fish and crustacean species in Asia (includes carps, tilapia, mandarin fish, snakehead, catfishes, freshwater crabs and prawns, milkfish, eels, and marine fish and penaeid shrimp), to mainly diadromous salmonid and penaeid shrimp species in Latin America and the Caribbean.

In general the farming or production systems employed by farmers within the different regions reflect the intended market (domestic or export) and value (high or low) of the cultured target species. Thus farming systems typically range from the use of lower-cost earthen pond-based extensive and semi-intensive production systems for the mass production of lower-value freshwater fish species (mainly cyprinids, tilapia and the diadromous milkfish) destined for local domestic consumption, to the use of more intensive pond, cage or tank-based production systems for the production of higher-value carnivorous fish species (marine fish, salmonids, eels, mandarin fish, snakehead) and crustaceans (marine shrimp, freshwater prawns, crabs, etc) for export or high-end domestic markets.

With the possible exception of Brazil (in the case of freshwater fish species), the bulk of aquaculture species produced within the selected Latin American countries were higher-value species (in marketing terms) destined for export to developed country markets, including salmonids (Chile) and marine shrimp (Brazil, Cuba, Ecuador, Mexico, Bolivarian Republic of Venezuela). A similar situation exists in the selected Asian countries (with the exception of freshwater food-fish species), where the bulk of marine finfish and shrimp production is also destined for export. It is also of interest to note that over 99.67 percent of global farmed shrimp production in 2005 (2 675 336 tonnes) was produced in developing countries (FAO, 2007) and exported mainly to the developed country markets of North America, Europe and Japan.

Finally, with the possible exception of the recent reduced growth observed in the production of the lower-value filter feeding fish species in China (FAO, 2007), the growth of fed-species within all three regions continues to exhibit double digit growth rates. The current major production constraints for fed-species are either market related (decreasing market prices due to increased production and/or international competition) or environmental (intensification of farming practices leading to eutrophication of receiving waterbodies, increasing disease occurrence and/or due to increasing concerns regarding food and feed safety).

3. REVIEW AND ANALYSIS OF AQUACULTURE FEEDS AND FEEDING

Feeding methods

Globally the feeding methods employed by farmers can be divided into three basic categories, namely:

- no feeding: fish/crustacean growth dependent upon the natural productivity of the waterbody or culture environment (typical of traditional extensive pond farming systems);
- endogenous feeding: fish/crustacean growth dependent upon the increased endogenous or *in-situ* production of natural food organisms and plants within the culture system either 1) indirectly through the application of substrates so as to increase the surface area available for natural food production (by using woody branches and plant stems or artificial substrates) and/or 2) directly through the application of chemical fertilizers and/or organic manures as a source of nutrients for natural animal and plant biota (typical of modified extensive pond farming systems);
- exogenous feeding: fish/shrimp growth dependent upon the external supply of feeds, either (i) in the form of single agricultural feed ingredients or simple feed mixtures/mashes (usually used as supplementary feeds in combination with endogenous feeding regimes), (ii) in the form of a single food item of high nutrient value (such as trash fish, marine invertebrates – worms, crabs, shrimp) and/or (iii) in the form of a formulated nutritionally complete compounded diet (the latter either produced on-farm or off-farm by a commercial feed compounder.

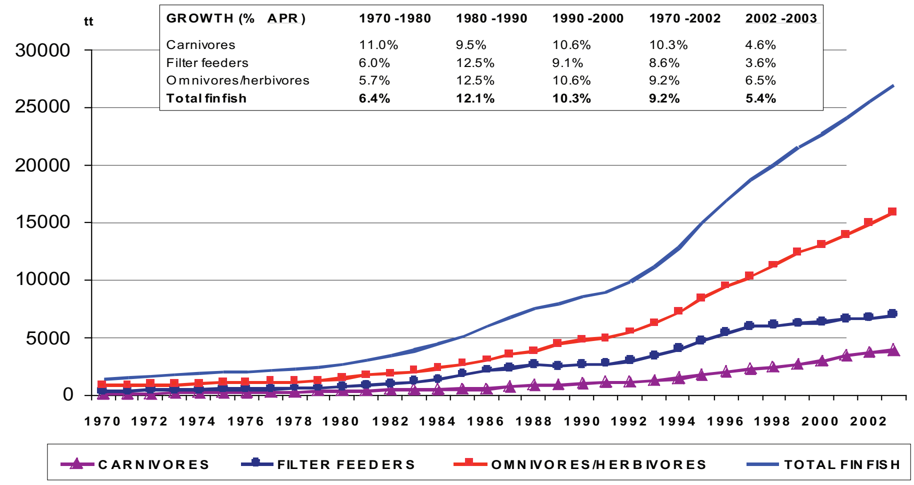
As with farming systems, the choice of the feeding method is based upon a variety of different factors (which in turn may vary from country to country and farmer to farmer), including the aim of the farming activity (local/home consumption or cash crop/export), the market value of the cultured species, the financial resources of the farmer and the local market availability of appropriate fertilizers and feeds. Thus feeding methods may range from the use of lower-cost endogenous feeding strategies based on the use of fertilizers and manures within controlled eutrophic or green-water extensive pond culture systems for the production of lower-value (in marketing terms) filter feeding and/or benthic detritivorous fish species (such as silver carp and bighead carp, mullet and milkfish, respectively), to the use of higher-cost nutritionally complete extruded pelleted diets for the production of high-value carnivorous marine finfish within intensive floating cage farming systems.

Fish and crustacean species

Although no official statistical information exists concerning the farming systems and feeding regimes employed by farmers for each of the major cultivated finfish and crustacean species within each of the regions targeted within this report, it is estimated that only 34.46 million tonnes or 54.7 percent of total global aquaculture production in 2005 was dependent upon endogenous and exogenous feeding (calculated from FAO, 2007), including:

- 8.79 million tonnes of filter-feeding carp species (major species – silver carp, bighead carp, rohu, catla: usually cultured as a polyculture of mixed species under extensive pond culture conditions using endogenous feeding and/or low-cost supplementary feeds);
- 16.85 million tonnes of herbivorous/omnivorous fish species (major species – grass carp, common carp, crucian carp, Nile tilapia, milkfish, mrigal carp, white amur bream, channel catfish, amur catfish, flathead grey mullet: usually cultured as a monoculture under semi-intensive and intensive culture conditions using endogenous and/or exogenous feeding);
- 3.96 million tonnes of crustaceans (major species: Pacific white shrimp, giant tiger prawn, Chinese river crab, oriental river prawn, giant freshwater prawn, red swamp crawfish, banana prawn, swimming crabs: usually cultured as a monoculture under semi-intensive or intensive culture conditions using endogenous and/or exogenous feeding); and
- 4.66 million tonnes of predominantly animal protein consuming or carnivorous fish species (major species: Atlantic salmon, rainbow trout, black carp, snakehead,

FIGURE 2
Finfish production by feeding habit (values expressed in thousand tonnes – tt, live weight equivalents)



Source: Tacon, Hasan and Subasinghe (2006)

Japanese eel, Japanese seabass, mandarin fish, Japanese amberjack, swamp eel, coho salmon, gilthead seabream, silver seabream, large yellow croaker, grouper) and 0.20 million tonnes of reptiles (major species: soft-shell turtle): usually cultured as a monoculture under semi-intensive or intensive culture conditions using exogenous feeding (complete pelleted feeds and/or trash fish).

Figure 2 shows the reported increase in production of cultured finfish by feeding habit, from which it is evident that the highest overall growth rate was recorded for carnivorous finfish species (10.3 percent), followed by omnivorous/herbivorous species (9.2 percent) and filter feeding species (8.6 percent). Of particular note, was the significant decline in the production rate of filter feeding species over the last decade.

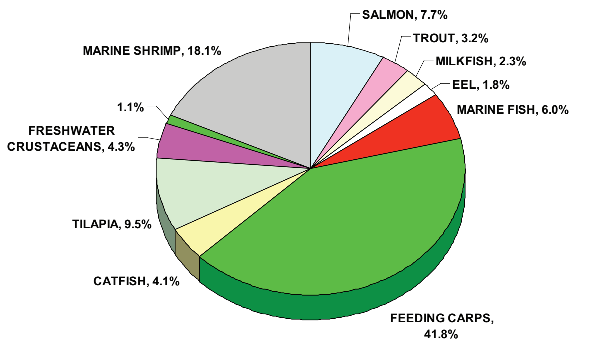
Compound aquafeed production

In most developed countries, almost all cultured finfish and crustacean species are currently reared on industrially compounded aquafeeds and total aquafeed production is annually reported. Unfortunately in most developing countries there is no precise statistical information concerning the percent of aquaculture production that is attributable to industrially compounded aquafeeds, farm-made aquafeeds or whole food items (such as trash fish), either by major cultured species group or farming system.

On the basis of the information presented in the three regional reviews (De Silva and Hasan, 2007; Flores-Nava, 2007; Hecht, 2007), total estimated compound aquafeed production within the 20 selected countries (which collectively accounted for 86.3 percent of total global aquaculture production by weight in 2003; FAO, 2007) was estimated to be just over 11.5 million tonnes (Latin America select – 1.2 million tonnes, Asia select – 10.30 million tonnes and sub-Saharan Africa select – 12 000 tonnes). These estimates compare very favourably with those reported by Tacon (2004a) of 1.3 and 10.9 million tonnes for the same selected countries in Latin America and Asia, respectively.

Tacon (2007) estimated that the global production of industrially compounded aquafeeds in 2005 was about 23.13 million tonnes (Figure 3). This figure compares favourably with Gill (2007), who estimated global aquafeed production to be approximately 25.4 million tonnes or 4 percent of global industrial animal feed production of 635 million tonnes in 2006.

FIGURE 3
Estimated global compound aquafeed production in 2005 for major farmed species (values expressed as % total aquafeed production, dry as fed basis)



Total estimated compound aquafeed production in 2005 – 23.13 million tonnes

Source: Tacon (2007)

Of particular note is the general trend within some regions, and in particular the Latin American region, toward the consolidation of the commercial aquafeed manufacturing sector, which in some cases has resulted in regionalization of markets, thus reducing local competition and consequently restricting types, presentations and even quality of products, e.g. Brazil, Chile and Mexico (Flores-Nava, 2007).

The important role played by government and national feed industry associations in setting policy guidelines and criteria for the sustainable development of the aquafeed manufacturing sector within the three target regions was particularly stressed. For example, government policy and feed associations can play critical roles included the establishment of good feed manufacturing practices (feed storage, quality control guidelines, record keeping and good on-farm feed management), the setting and/or removal of feed ingredient import restrictions and duties and through the establishment of improved customs clearance procedures and export incentives. Apart from ensuring the sustainable development of the aquafeed manufacturing sector, attention to the above mentioned issues would in turn ensure that farmers would receives a consistent cost-effective quality product targeted to the dietary needs of the cultured species (FAO, 2001).

Farm-made aquafeed production

Except for Asia, where total farm-made aquafeed production was estimated at 19.3 million tonnes (De Silva and Hasan, 2007), there is no accurate information on the current production of farm-made aquafeeds in the selected sub-Saharan (except Nigeria) and Latin American countries. Hecht (2007) noted that approximately 70 percent of the 35 570 tonnes of aquafeed used Nigeria consisted of farm-made feeds. According to De Silva and Hasan (2007) farm-made aquafeed production within the selected Asian countries was as follows:

- China – 10.88 million tonnes (compared with 7.8 million tonnes of industrially compounded aquafeeds);
- India – 6.16 million tonnes (compared with 238 883 tonnes of compound aquafeeds);
- Viet Nam – 800 000 tonnes (compared with 696 000 tonnes of compound aquafeeds);
- Thailand – 762 173 tonnes (compared with 822 500 tonnes of compound aquafeeds);
- Philippines – 384 896 tonnes (compared with 204 396 tonnes of compound aquafeeds); and
- Indonesia – 275 850 tonnes (compared with 490 000 tonnes of compound aquafeeds).

However, no indication was given if farm-made aquafeed production was based on a wet, semi-moist or dry weight basis.

The important role played by farm-made aquafeeds within extensive and semi-intensive pond farming systems and in particular for the production of lower value, freshwater fish species for home consumption was particularly highlighted. For example, in India farm-made aquafeeds represent 96.3 percent of the total feed used by farmers (De Silva and Hasan, 2007), and provide the mainstay of feed inputs within the selected sub-Saharan countries (Hecht, 2007).

4. PROBLEMS AND CONSTRAINTS

The following problems and constraints to feeds and feeding were reported within the regional reviews, namely:

Use of trash fish as fish feed

A problem reported in some Asian and sub-Saharan countries has been due to the increased competition between humans and aquaculture for the use of low value fish or 'trash fish' as feed (Edwards, Tuan and Allan, 2004; FAO, 2004; Hecht, 2007). Fish species generally considered under this category include small pelagic filter feeding species such as anchovy, herring, sardines, pilchards, omena, pony fish and small sergestid shrimp.

Although there are no official estimates concerning the amount of low value fish used in aquaculture, Allan (2004) and Tacon (2004a) have estimated that the total use is between 5 and 6 million tonnes, respectively. For example, according to D'Abramo, Mai and Deng (2002) the marine aquaculture sector in mainland China in 2000 consumed 4 million tonnes of 'trash fish'. Similarly, Edwards, Tuan and Allan (2004) estimated that the total use of 'trash fish' by the aquaculture industry in Viet Nam was between 176 420 and 323 440 tonnes, with trash fish representing an estimated 36 percent of the total marine fisheries catch in 2001. The above estimates also agree with the disposition of the global fisheries catch (FAO, 2007), for which the difference between the proportion of total landings destined for non-food uses (28.28 million tonnes) and reduction (21.38 million tonnes) in 2003 was around 6.9 million tonnes (FAO, 2007).

Apart from the potential environmental polluting effect and disease risks of using non-processed trash fish products as aquaculture feed, there are growing concerns that the increasing demand for these products by the aquaculture sector may result in increasing fishing pressure on available fish stocks (FAO, 2004) and drive up the cost of 'trash fish' and out of the economic grasp and reach of the poor and needy for direct human consumption (Edwards, Tuan and Allan, 2004; Normile, 2002). For example, Allan (2004) reported that the price of 'trash fish' in Viet Nam has doubled due to the increasing demand for the product from the domestic aquaculture sector.

Fish species reportedly commonly being fed trash fish include marine and freshwater carnivorous fish species in China (D'Abramo, Mai and Deng, 2002) and Viet Nam (Edwards, Tuan and Allan, 2004), and more recently tuna in Mexico (Flores-Nava, 2007 and personal observation). For example, according to Allan (2004) the on-growing of wild-caught southern bluefin tuna in Australia requires 50 000 to 60 000 tonnes of pilchards or 'baitfish' for a tuna biomass increase of 3 000 tonnes. This is equivalent to a 'pelagic fish' to 'farm fish' conversion ratio of 16.6:1 – 20:1. Similar conversion ratios have been reported by other authors for tuna, with mean food conversion ratios for on-growing tuna in the Mediterranean region typically ranging from 15 to 20:1, to as low as 8:1 and 12.5:1 for fingerlings and juveniles using baitfish in Japan (Ottolenghi *et al.,* 2004).

Use of fishmeal and fish oil as fish feed

One of the biggest problems and constraints facing the animal and aquafeed industry is the current dependence of the aquaculture sector upon fishmeal and fish oil as a cost-effective source of high quality animal protein and essential dietary lipids (Barlow, 2003; FIN, 2004; Hardy and Tacon, 2002; Huntington, 2004; Huntington *et al.,* 2004; New and Wijkstrom, 2002; Pike, 2005; Seafeeds, 2003). This dependency is particularly strong for those higher value species feeding high on the aquatic food chain, including all farmed carnivorous finfish species and most omnivorous/scavenging crustacean species (Allan, 2004; Hardy, 2003; Pike and Barlow, 2003; Tacon, 2004a; Zaldivar, 2004). The apparent higher dependency of these cultured species for fishmeal and fish oil is primarily due to their more exacting dietary requirements for high quality animal protein, essential omega-3 fatty acids and essential trace minerals (Hardy *et al.*, 2001; Pike, 1998).

According to Tacon, Hasan and Subasinghe (2006) the aquafeed sector consumed about 52.6 percent and 86.8 percent of the total global production of fishmeal (Figure 4) and fish oil (Figure 5) in 2003, respectively.

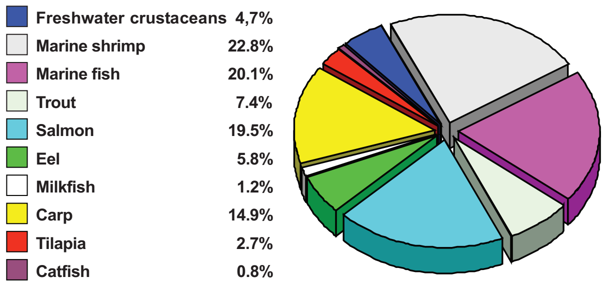
It is important to note here that the total estimated amount of fishmeal and fish oil used within aquafeeds has grown over three-fold from 963 to 2 936 thousand tonnes and from 234 to 802 thousand tonnes from 1992 to 2003, respectively (Tacon, Hasan and Subasinghe, 2006). However, this increase in usage is in line with the almost three-fold increase in total finfish and crustacean aquaculture production over this period, from 10.9 to 29.8 million tonnes from 1992 to 2003 (FAO, 2007).

Apart from the fact that the total global supplies of fishmeal and fish oil are limited in terms of quantity and availability (fishmeal and fish oil supplies fluctuated between 5 and 7 million tonnes and 0.7–1.3 million tonnes over the past decade, respectively) (FAO, 2007), there is increasing competition for direct human consumption of many the pelagics currently used to make fishmeal for animal feeding (Hecht, 2007; Wray, 2001; Zaldivar, 2004).

Although Latin American countries are currently generally self sufficient in fishmeal and fish oil supplies, the Asian and sub-Saharan countries surveyed in the regional reviews were all net importers of fishmeal and/or fish oil. In 2003, China alone imported 803 thousand tonnes of fishmeal, accounting for 22.5 percent of total global fishmeal imports (FAO, 2005) and for about one third of world soybean imports (Tacon, 2005a; Tuan, Fang and Cao, 2004);

FIGURE 4

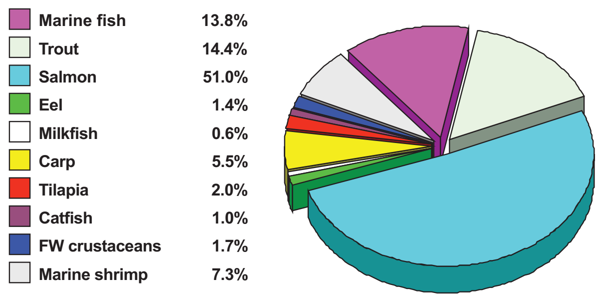
Estimated global use of fishmeal (percentage of dry as fed basis) within compound aquafeeds in 2003 by major species. Total estimated fishmeal used in aquafeeds was 2 936 thousand tonnes or 52.6% of total reported world production in 2003



Source: Tacon, Hasan and Subasinghe (2006)

FIGURE 5

Estimated global use of fish oil (percentage of dry as fed basis) within compound aquafeeds in 2003 by major cultivated species. Total estimated fish oil used in aquafeeds in 2003 was 802 thousand tonnes or 86.8% of total reported world production



Source: Tacon, Hasan and Subasinghe (2006)

Other reported regional constraints

In addition to the use of fishmeal and fish oil, the following other regional problems and constraints were reported, namely:

- Realization that the bulk of small-scale farmers in sub-Saharan Africa and to a lesser extent within many of the selected Asian and Latin American countries, do not have the financial resources to purchase feed and/or nutrient inputs for their aquaculture operations;
- General lack of resident expertise and training opportunities in aquaculture nutrition and feed manufacturing technology within most sub-Saharan African countries, including feeds and feeding based development projects and undergraduate and postgraduate university training courses (Hecht, 2007);

- Trend toward the development and use of more environmentally friendly feeds and feeding regimes, including the increasing development and use of highly digestible extruded aquafeeds by the commercial aquafeed sector, and in particular within those countries where environmental degradation and water pollution are major/potential aquaculture development issues (e.g. Chile – Tacon, 2005b);
- General lack of information and regulation concerning the presence of heavy metal and other environmental contaminants within aquafeeds (and consequently the cultured aquaculture product) and possible short and long term effects on human health, including possible export/import restrictions (De Silva and Hasan, 2007; Tacon, 2005b);
- General lack of ready available practical information concerning the dietary nutrient requirements of the major fed aquaculture species, including up-to-date information concerning aquaculture nutrition, feed ingredient usage, feed formulation, feed manufacture and on-farm feed management, including the development and use of appropriate on-farm research methods;
- Recognition of the increasing competition and limited availability of available land and freshwater for inland-based aquaculture operations (De Silva and Hasan, 2007), and the need to further explore and expand marine-based off-shore aquaculture technologies and opportunities; and
- Recognition of the global importance of China in the production of farmed aquatic produce, including importation of key feed ingredients and nutrients, and possible long terms effects on global fish supplies, fish prices and the long term global sustainability of the aquaculture sector (Hishamunda and Subasinghe, 2003; Tacon, 2005a).

5. RECOMMENDATIONS CONCERNING FEEDS AND NUTRIENT USE

On the basis of the country reviews, regional syntheses/reviews and published information/literature, the following recommendations and policy guidelines concerning feeds and nutrient use can be made:

- The need for governments within major aquaculture producing countries to limit the use of 'trash fish' or low value fish species for use as feed for the production of high value fish or shellfish species, and in particular within those countries where trash fish is consumed directly by the rural poor;
- The need for governments within major aquaculture producing countries to prohibit the recycling of aquaculture products within aquafeeds, and in particular the intra-species recycling of aquaculture products, for strict biosecurity concerns and potential accumulation of environmental contaminants;
- The need for governments to encourage the increased use and recycling of adequately processed terrestrial animal by-product meals within compound aquafeeds as a means of safely recycling animal by-products from terrestrial warm-blooded farm animals through a completely different animal food chain;
- The need for governments to promote and encourage the aquaculture sector to utilize the largely untapped existing feed-grade waste streams within the fisheries sector, including fisheries bycatch and discards and fishery processing wastes (Bechtel, 2003; Li *et al.*, 2004; Rathbone *et al*., 2001);
- The need for governments to further encourage and promote the culture of aquatic species feeding low on the aquatic food chain, which can utilize locally available nutrient and aquatic resources, including marine and freshwater aquatic plants, filter feeding molluscs and fishes, herbivorous/omnivorous finfish and crustacean species and aquatic species tolerant of poor water quality;
- The need for governments to further promote and encourage the integration of aquaculture with other agricultural farming activities such as irrigation, crop production and animal husbandry and by so doing improve resource use

efficiency and productivity, including water and nutrient use and the development of organic aquaculture production systems (Tacon and Brister, 2002);

- The need for governments to further promote and encourage the development of new innovative floc-based zero water exchange culture systems to further reduce the dependence of the marine shrimp aquaculture sector upon fishmeal and fish oil as feed inputs (Tacon *et al*., 2002; Tacon, Nates and McNeil, 2005);
- As stated in the FAO Code of Conducted for Responsible Fisheries "States should encourage the use of fish for human consumption and promote consumption of fish whenever appropriate" (FAO, 1995), and discourage the use of food-fish fit for human consumption for animal feeding; and
- In line with the Rome Declaration on World Food Security and the World Food Summit Plan of Action, that aquaculture activity do no harm to the existing food supplies of the poor, but rather help by providing much needed affordable aquatic food produce and employment opportunities within both inland and coastal rural communities (Tacon, 2001).

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Feeds and fertilizers: the key to long-term sustainability of Asian aquaculture

Sena S. De Silva[1]
School of Life and Environmental Sciences, Deakin University
PO Box 423, Warrnambool, Victoria 3280
Australia
Mohammad R. Hasan
Aquaculture Management and Conservation Service
FAO Fisheries and Aquaculture Department, Rome 00153
Italy

De Silva, S.S. and Hasan, M.R. 2007. Feeds and fertilizers: the key to long-term sustainability of Asian aquaculture. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 19–47.

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[1] Network of Aquaculture Centres in Asia-Pacific, Bangkok, PO Box 1040, Kasetsart Post Office, Bangkok, 10903, Thailand.

SUMMARY

Asian aquaculture is dominated by inland, semi-intensive finfish culture and production has been increasing over the years. However, the rate of increase is decreasing, except in Viet Nam, and overall production is likely to stabilize around year 2015. The major factors that will sustain aquaculture production in Asia are feeds and feed management. Asian aquaculture is still largely a rural and semi-intensive activity, baring exceptions such as shrimp culture, and consequently the sector to a large extent is dependent on farm-made feeds. However, the use of commercial feeds in Asia is also increasing. There have been substantive improvements in farm-made feed formulation and manufacturing. Throughout the region there is an increase in the number of small-scale processors who make customised feeds, according to required specifications and this has lead to greater feed efficacy, reduction in feed costs and improved feed quality. There is an urgent need to investigate ways and means to further improve farm-made feeds through suitable research and development programmes in collaboration with farmers and small scale processors and to develop appropriate policies to encourage growth in this sector. The first step towards achieving these goals will be to assess the types of feed produced by small-scale producers and the magnitude of the sector and to evaluate the current efficacies of non-commercial feeds.

Asian finfish mariculture is almost totally dependent on the use of trash fish, a resource that is declining and a practice that results in much environmental degradation. As such there is an urgent need to encourage farmers to change to farm-made and or commercial feeds. If this is not accomplished the sector is unlikely to be sustainable.

Asia is a net importer and the biggest user of fishmeal and fish oil. It is therefore not immune to global issues in respect of fishmeal and fish oil usage in aquafeeds. Overall, the use of animal by-products and fishing industry wastes for aquafeeds is restricted. There is a need to encourage the use of such ingredients in aquafeeds. Although many studies have been undertaken on fishmeal replacement the results are rarely translated into practices, and as such there is a need to bring about an effective dialogue between research and development and the feed industry. Throughout the region there are growing concerns with regard to feed quality and consequently suitable guidelines and certification processes have to be introduced.

1. INTRODUCTION

Over the last three decades food fish production has become the domain of the developing world, in particular Asia (Delgado *et al*., 2003). In 2004, world aquaculture contributed nearly 33 percent to the global food fish supply, amounting to 54.8 million tonnes and valued at US$67.3 billion. To this, Asia contributed 91.2 percent (49.98 million tonnes), valued at US$55.1 billion (FAO, 2006). Asia has an estimated human population of 3.68 billion that is expected to increase to 4.78 billion by 2025 (http://esa.un.org/unpp/). Most of the worlds major fish stocks are over fished and catches in many of the major fisheries are either static or are declining. Aquaculture is the only option to increase fish production and to narrow the gap between supply and demand. Because of its rapid growth in the last three decades the aquaculture sector now faces new and demanding environmental, social, resource allocation and technological challenges. These must now be addressed and overcome to maintain the momentum in the sector.

This paper considers the current use of feeds and other nutrients in Asian aquaculture as key components for the sustainable development of the sector in the next two to three decades. This synthesis is mostly based on comparable analyses undertaken for Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam, which are the major contributors to aquaculture production in the region, a review of the relevant literature and FAO (2006) production statistics.

Recent trends in aquaculture in the region are briefly summarized to place the significance of feeds and feeding into perspective within the context of Asian aquaculture. This provides the background for the analysis and is used to assess possible future trends that might impact on the sustainable development of the sector as a whole.

1.1 Brief review of the Asian aquaculture sector

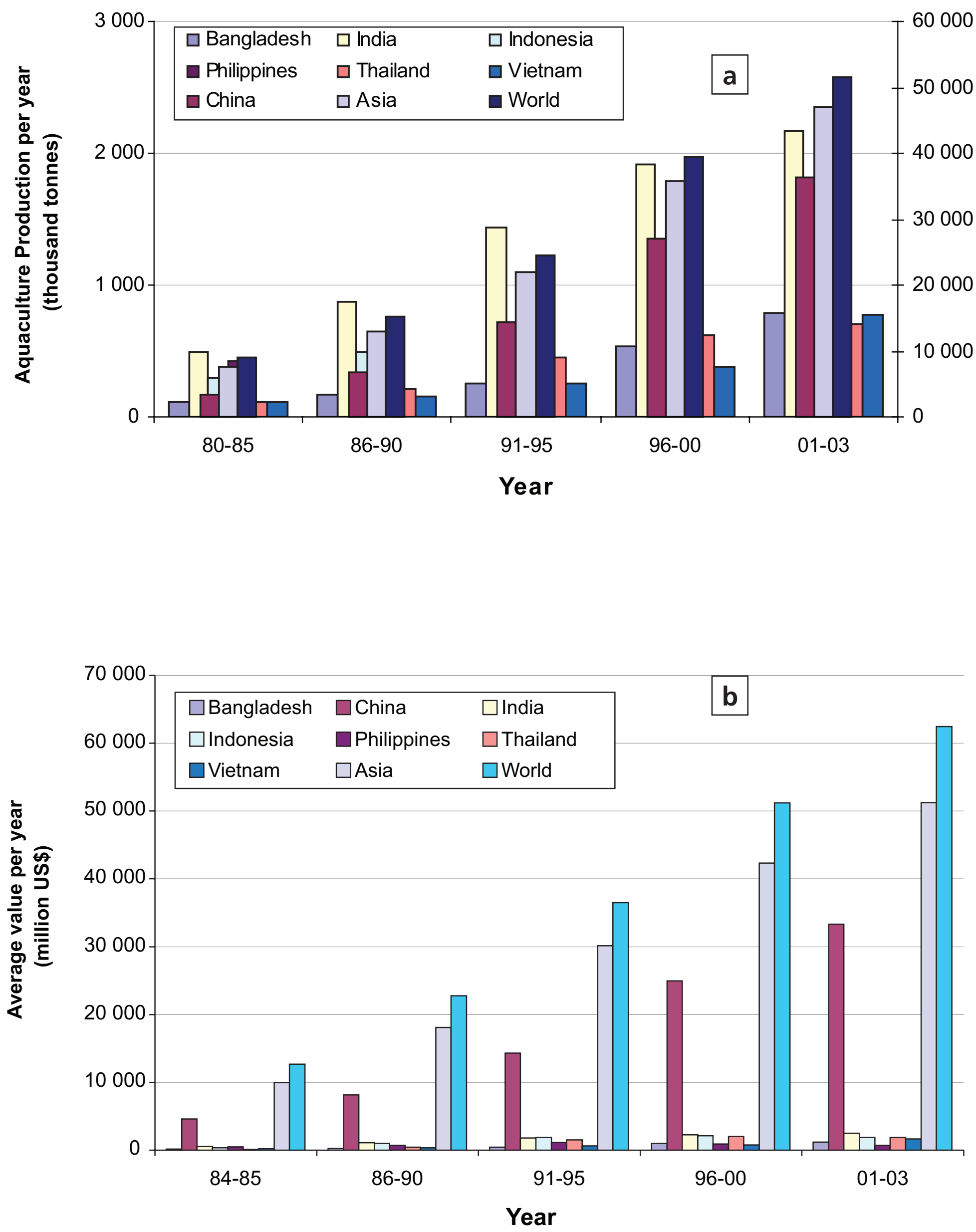
The trends and most of the key aspects of global and Asian aquaculture up to the year 2000 are summarized in NACA/FAO (2001). Table 1 summarizes the trends and developments in freshwater, brackish-water and marine aquaculture for the 15 year period from 1995 to 2004. From these data it is evident that aquaculture production by volume and value has increased substantially in all of the major producer countries. Over the 15 year period the seven countries, which form the basis of this review, contributed over 85 percent to the total Asian aquaculture production and over 70 percent globally. However, the contribution by value of marine aquaculture has remained below 50 percent of the global total and there is no discernable up or downward trend in this regard (Table 1). The data also clearly show the dominance of China in aquaculture production in all three environments.

Aquaculture in the seven countries was dominated by finfish production (Table 2). The seven countries contributed in excess of 90 percent to Asian and 80 percent to global fish production, although the bulk of finfish produced are relatively low value species. These trends are further summarized in Figures 1 to 4, using five year averages for the period 1980 to 2004. The trends can be summarized as follows:

- aquaculture production, by volume and value, has increased significantly in all of the countries under consideration;
- the main contributor has been China;
- marine and freshwater aquaculture have contributed almost equally to the total production (including seaweeds and molluscs);
- in terms of finfish and crustaceans, fresh and brackish-water aquaculture production is considerably higher than the output from mariculture; and
- apart from Viet Nam, there has been a significant decrease in the rate of growth in production in Asia and globally.

In a nutshell, aquaculture production is still increasing in most countries in Asia and globally. However, the rate of increase is declining and is likely to reach a plateau within the next two decades. As such, it is imperative that measures are taken to curtail the decline in the growth rate of the sector.

FIGURE 1
Annual mean aquaculture production by volume (a) and value (b) in the seven target countries, Asia and the world for the period 1980–2004. The mean is based on five-year averages, except for the period 2000–2004



Source: FAO (2006)

TABLE 1
Freshwater, brackish-water and marine aquaculture production by volume and value (excluding aquatic plants) in Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam, for 1995, 2000 and 2004

	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam	Asia	%Asia	World	%World
Production (tonnes)											
1995											
Brackish	45 735	78 416	70 000	361 247	237 091	265 889	71 816	1 226 824	92.1	1 556 967	72.6
Freshwater	271 338	9 407 600	1 588 799	279 845	97 664	200 782	295 933	12 633 079	96.1	13 529 722	89.7
Marine	0	6 369 637	8	0	26 829	92 833	13 320	7 817 311	83.2	9 295 327	70.0
Total	**317 073**	**15 855 653**	**1 658 807**	**641 092**	**361 584**	**559 504**	**381 069**	**21 677 214**	**91.2**	**2 438 2016**	**81.1**
2000											
Brackish	86 944	217 994	96 715	422 802	241 455	319 171	93 502	1 584 101	93.3	2 134 481	69.3
Freshwater	570 176	15 169 365	1 844 236	363 111	112 033	271 012	365 015	19 268 522	97.0	20 420 935	91.6
Marine	0	9 193 312	1253	2587	40 375	147 972	40 000	10 627 795	88.7	12 918 891	73.0
Total	**657 120**	**24 580 671**	**1 942 204**	**788 500**	**393 863**	**738 155**	**498 517**	**31 480 418**	**94.0**	**35 474 307**	**83.4**
2004											
Brackish	97 537	789 435	120 367	547 008	262 555	406 988	339 555	2 714 471	94.4	3 369 563	76.1
Freshwater	817 215	18 514 778	2 351 968	488 079	180 875	365 478	703 827	24 426 877	95.9	25 751 633	90.9
Marine	0	11 310 785	0	22 955	68 790	400 400	155 235	13 333 283	89.7	16 360 181	73.1
Total	**914 752**	**30 614 998**	**2 472 335**	**1 058 042**	**512 220**	**1 172 866**	**1 198 617**	**40 474 631**	**93.8**	**45 481 377**	**83.4**
Value (US$ thousand)											
1995											
Brackish	204 784	588 120	485 034	1 265 468	1 084 858	1 619 858	397 517	6 174 534	91.4	7 471 128	75.6
Freshwater	410 477	8 993 265	1 461 414	684 320	163 399	217 869	488 290	15 451 048	80.4	17 756 250	70.0
Marine	0	6 122 494	11	0	5 558	34 591	14 652	10 317 059	59.9	13 947 110	44.3
Total	**615 261**	**15 703 878**	**1 946 459**	**1 949 787**	**1 253 815**	**1 872 318**	**900 458**	**31 942 641**	**75.9**	**39 174 488**	**61.9**
2000											
Brackish	239 218	1 307 964	806 473	1 381 333	541 101	2 226 488	440 297	7 428 577	93.5	9 165 349	75.8
Freshwater	799 884	14 941 990	1 704 376	854 825	121 295	246 009	511 021	21 594 939	88.8	24 410 584	78.6
Marine	0	8 067 186	331	9 537	18 332	41 349	40 000	11 825 944	69.1	17 502 750	46.7
Total	**1 039 102**	**24 317 140**	**2 511 179**	**2 245 695**	**680 728**	**2 513 846**	**991 318**	**40 849 460**	**84.0**	**51 078 683**	**67.2**
2004											
Brackish	244 789	2 683 980	718 936	1 434 487	493 448	1 175 581	1 232 614	8 585 414	93.0	10 307 611	77.7
Freshwater	1 118 391	19 870 645	2 217 543	504 489	161 736	349 589	1 05 5741	28 452 981	88.8	31 755 255	79.6
Marine	0	8 314 984	0	191 028	45 670	61 456	155 235	12 990 642	67.5	21430 417	40.9
Total	**1 363 180**	**30 869 609**	**2 936 479**	**2 130 004**	**700 854**	**1 586 626**	**2 443 589**	**50 029 036**	**84.0**	**6 3493 284**	**66.2**

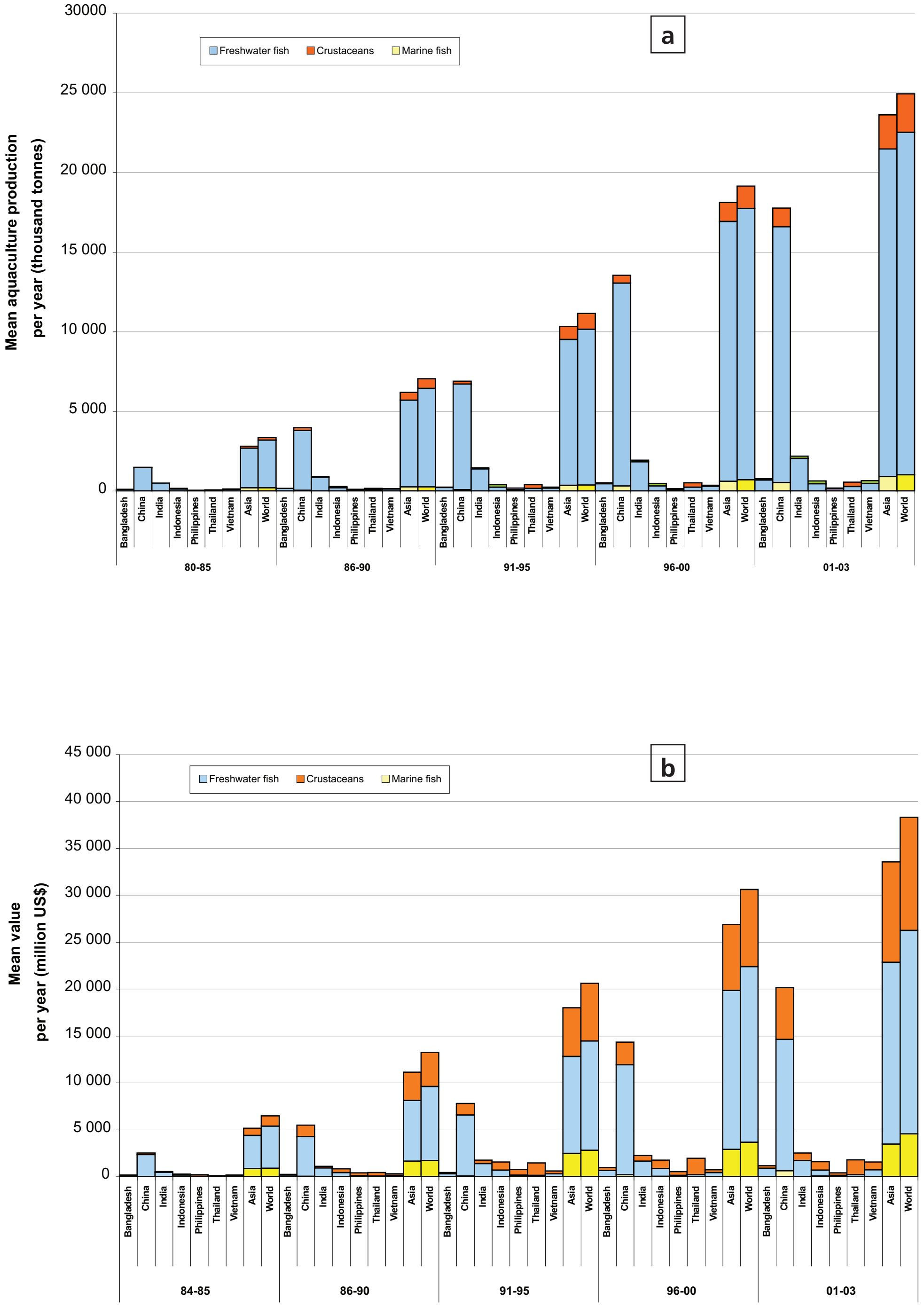
Source: FAO (2006)

TABLE 2
Aquaculture production by volume and value of finfish, crustaceans and molluscs in Bangladesh, China, India, Indonesia, the Philippines, Thailand, and Viet Nam, for 1995, 2000 and 2004, in Asia and globally

	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam	Asia	%Asia	World	%World
Production (tonnes)											
1995											
Finfish	283 043	9 493 597	1 588 799	492 578	241 703	197 904	295 933	13 420 931	93.8	14 994 370	84.0
Crustaceans	34 030	181 880	70 000	148 514	93 275	268 550	71 816	906 026	95.8	1 101 693	78.7
Molluscs	0	6 162 731	8	0	26 606	92 833	13 320	7 295 062	86.3	8 230 344	76.5
Total	**317 073**	**15 838 208**	**1 658 807**	**641 092**	**361 584**	**559 287**	**381 069**	**21 622 019**	**91.4**	**24 326 407**	**81.2**
2000											
Finfish	592 473	15 074 183	1 827 636	641 677	315 865	268 995	365 015	20 013 066	95.4	22 745 339	83.9
Crustaceans	64 647	807 095	113 315	146 823	46 819	319 788	93 502	16 44 365	96.8	1 820 196	87.5
Molluscs	0	8 607 050	1 253	0	31 179	147 972	40 000	9 686 477	91.1	10 771 451	82.0
Total	**657 120**	**24 488 328**	**1 942 204**	**788 500**	**393 863**	**736 755**	**498 517**	**31 343 908**	**94.1**	**35 336 986**	**83.5**
2004											
Finfish	839 585	17 834 881	2 300 350	803 135	437 051	349 356	761 566	24 757 653	94.2	28 165 039	82.8
Crustaceans	75 167	1 995 164	171 985	241 874	44 216	418 510	281 816	3 338 706	96.7	3 679 753	87.7
Molluscs	0	10 438 313	0	12 991	30 953	400 400	155 235	11 998 256	92.0	13 255 852	83.3
Total	**914 752**	**30 268 358**	**2 472 335**	**1 058 000**	**512 220**	**1 168 266**	**1 198 617**	**40 094 615**	**93.8**	**45 100 644**	**83.4**
Value (US$ thousand)											
1995											
Finfish	410 810	8 781 638	1 461 414	1 084 314	469 697	207 479	488 290	18 681 500	69.1	23 686 176	54.5
Crustaceans	204 451	1 122 471	485 034	865 473	779 135	1 628 238	397 517	5 894 083	93.0	6 976 619	78.6
Molluscs	0	5 721 267	11	0	4 983	34 591	14 652	7 191 233	80.3	8 332 397	69.3
Total	**615 261**	**15 625 376**	**1 946 459**	**1 949 787**	**1 253 815**	**1 870 308**	**900 458**	**31 766 816**	**76.1**	**38 995 192**	**61.9**
2000											
Finfish	788 363	13 161 581	1 649 596	1 383 896	382 538	234 280	511 021	23 119 776	78.3	31 048 878	58.3
Crustaceans	250 739	3 640 098	861 253	861 799	293 363	2 231 269	440 297	8 990 595	95.4	10 088 486	85.0
Molluscs	0	7 173 792	331	0	4 827	41 349	40 000	8 318 827	87.3	9 515 080	76.3
Total	**1 039 102**	**23 975 471**	**2 511 179**	**2 245 695**	**680 728**	**2 506 898**	**991 318**	**40 429 197**	**84.0**	**50 652 444**	**67.0**
2004											
Finfish	1 038 702	15 937 967	1 950 815	939 396	434 691	311 556	1 142 349	27 888 121	78.0	37 920 700	57.4
Crustaceans	324 478	7 201 207	985 663	1 053 692	262 596	1 199 547	1 146 005	12 849 252	94.7	14 360 890	84.8
Molluscs	0	6 557 577	0	136 764	3 567	61 456	155 235	8 055 705	85.8	99 71 105	69.4
Total	**1 363 180**	**29 696 751**	**2 936 479**	**2 129 852**	**700 854**	**1 572 559**	**2 443 589**	**48 793 079**	**83.7**	**62 252 695**	**65.5**

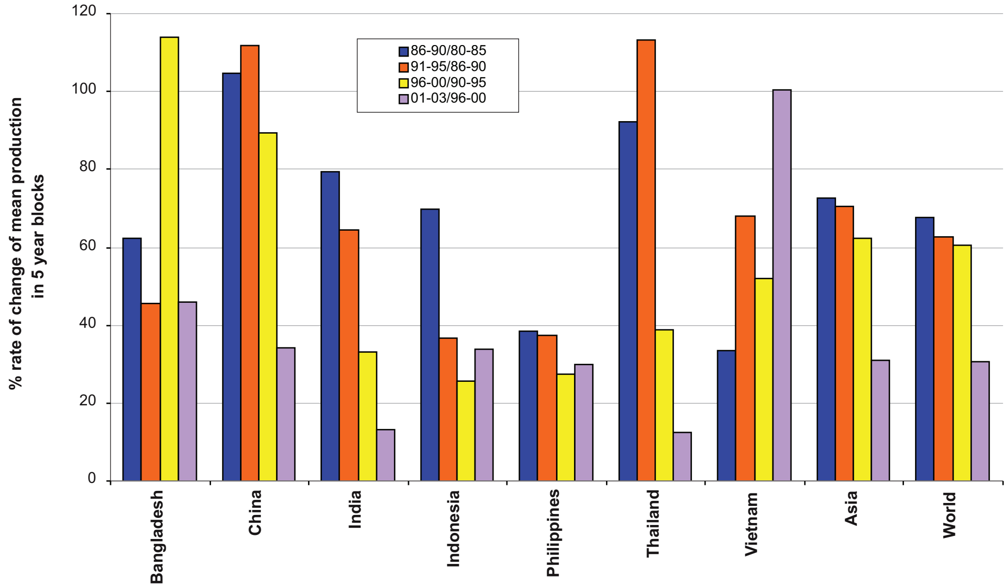
Source: FAO (2006)

FIGURE 2
Mean aquaculture production by volume (a) and value (b) by species groups for the period 1980–2004 in Asian countries



Source: FAO (2006)

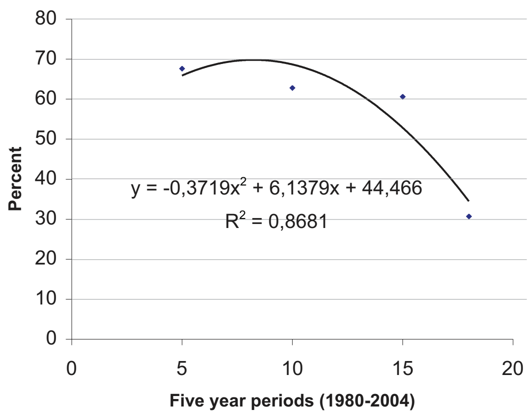
FIGURE 3
Percent rate of change in mean aquaculture production (in five year blocks) for selected Asian nations, whole of Asia and the world



Source: calculated from FAO (2006)

1.2 Strategies for increasing aquaculture production in a sustainable manner

FIGURE 4
Percent change in Asian aquaculture production over time



Source: calculated from FAO (2006)

While retaining a rural base, many factors were responsible for the upsurge in Asian aquaculture production. In addition to technological advances and improvements, the foremost factors that led to the rapid growth of aquaculture in the region were the increasing gap between food fish demand and supply and the subsequent support by governments to develop rural and industrial scale aquaculture. The main technological advances that contributed to the increases in production were:

- advances in hypophysation techniques and the virtual elimination of the dependency on wild juveniles (apart from a few cultured species);
- advances in husbandry techniques, such as the adoption of "polyculture" systems and improved management procedures;
- genetic improvement of a number of species and the development of monosex tilapia culture
- improvements in disease prevention and control; and
- improvements in feed formulations and manufacture and feeding practices.

The surface area used for aquaculture in Asia has been increasing. The area currently used for aquaculture in the region is summarized in Table 3. There is little scope to increase production by increasing the area under culture, especially in inland waters. The reason for this is although Asia has the largest inland/freshwater resources

TABLE 3
Estimated area (ha) available and/or documented to be used for aquaculture in different environments in seven Asian countries

Environment	Country						
	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam
Freshwater (finfish)							
Ponds	305 025	1.858×10^6	247 500	97 821	14 531	118 002	120 000
Depressions	5 488		130 000			2 007	
Reservoirs/lakes		2.334×10^6	270 000		219 000		340 000
Cages				466*		59	
Others		471 600		151 414**		23 432**	580 000**
Freshwater (prawn etc)							
Ponds			41 870				
Brackish water							
Pond	217 877		154 600	370 824	239 323	83 919	
Cages							
Marine				-			
Cage units		715 750		196 198			660 000***

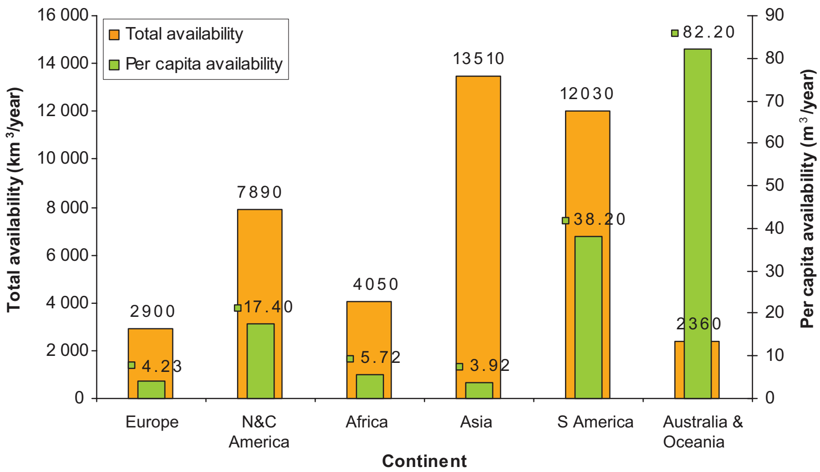
* Inland cages; **primarily paddy fields; *** tidal flats; empty spaces = no data

Source: data for Bangladesh, China, India, Indonesia, Philippines, Thailand and Viet Nam were obtained respectively from Barman and Karim (2007); Cen and Zhang (1999); Ayyappan and Ahamad Ali (2007); Nur (2007); Sumagaysay-Chavoso (2007); Thongrod (2007); and Hung and Huy (2007)

among all continents, the per caput availability is lowest (Nguyen and De Silva, 2006; Figure 5). As such, increasing competition for this relatively scarce primary resource (in addition to the demand for land) will probably not permit significant expansion of inland aquaculture, except perhaps the use of reservoirs for cage and cove culture and culture-based fisheries (De Silva, 2003). On the other hand, unplanned and overly ambitious developments in reservoir cage culture can be counter productive, as has been the case in certain Asian countries (Abery *et al*., 2005).

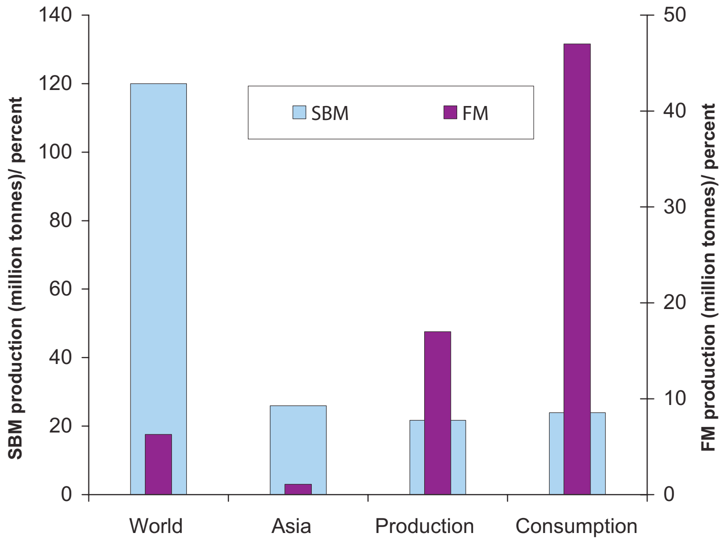
In essence there are two possible strategies to increase future aquaculture production in Asia. These are genetic improvements and advances in feed and feed technology. The most notable advances in genetic improvements have been made for salmonids and tilapias (Gedram, 2000) and these have to be emulated for some of the more important aquaculture species in Asia. In following this approach care has to be taken to preserve the genetic integrity of individual species and to conserve biodiversity. Some genetic manipulations such as the hybridisation of the Asian catfish (*Clarias macrocephalus*) with the African catfish (*C. gariepinus*) could have long term negative impacts on

FIGURE 5
Total and per caput inland water availability per continents



Source: Nguyen and De Silva (2006)

FIGURE 6
Global and Asian production of soybean meal and fishmeal (in million tonnes) and the percent contribution by Asia to global production and consumption



Source: Tacon (2004)

natural population structure and the conservation of biodiversity (Na-Nakorn, 2005) and could lead to negative public perception on aquaculture developments.

Developments in feeds and feed management have a crucial role to play in the future expansion of Asian aquaculture, particularly with respect to the rapidly increasing demand for commercial feeds by the shrimp, marine and freshwater finfish sectors (Chamberlain, 1993; Gill, 1997; New and Csavas, 1995; Tacon and De Silva, 1997; De Silva, 1999; Hasan, 2001; Tacon, 2004; Tacon, Hasan and Subasibghe, 2006). The demand for commercial aquaculture feeds has also recently become more contentious, particularly with regard to the supply of fishmeal and fish oil. Aquaculture has become the single largest consumer of these commodities of all animal husbandry sectors. Aquaculture's share of fishmeal use has increased from 10 percent in 1988 to 46 percent in 2002 (Barlow and Pike, 2001; Pike, 2005). Similarly, there has been a drastic increase in the share of fish oil usage from 16 percent in 1988 to 81 percent in 2002. Pike (2005) further predicted that in 2012, aquaculture will use 50 and 88 percent fishmeal and fish oil, respectively. Aquaculture's share of total fishmeal and fish oil use is therefore expected to increase, respectively, from 46 percent and 81 percent in 2002, to 50 percent and 88 percent by 2012. The consequences of these trends to the Asian region, that accounts for over 90 percent of global aquaculture production, is immediately obvious. Moreover, the demand and use of fishmeal in some of the emerging aquaculture countries in Asia is increasing rapidly. For example, Viet Nam already uses approximately 62 500 tonnes of fishmeal per year, solely for aquaculture (see Figure 6 and also refer to www.gafta.com/fin/finfacts3.html.)

2. FEEDS AND FEEDING PRACTICES IN ASIAN AQUACULTURE

Aquaculture is very diverse because of the number of species cultured, singly and or in combination, the differences in the environment – freshwater, brackish water or marine, the intensity of the practice, the nature of the containment – ponds, cages, raceways, etc, as well as the socio-economic *milieu* in which it occur. This diversity is similarly reflected in the array of different feeds, feeding practices and the use of organic or inorganic fertilizers. For the purposes of this paper, feeds and feeding practices in Asian aquaculture are considered in relation to culture intensity, i.e. extensive, semi- and intensive culture practices.

Feed efficacy also has the potential to bring about major changes in culture practices, even in the case of small-scale, rural aquaculture enterprises. For example, in the Mekong Delta in southern Viet Nam it has been reported that high feed costs in pangasiid cage culture has brought about a significant shift to pond culture (Hung and Merican, 2006). The significant point is that the overall production cost per kg ranged from VND 8 000 to 11 000 in ponds as opposed to VND 8 153 to 11 619 in cages (US$1.00 = VND 15 000), of which feeds accounted for 78 to 90 percent of total production costs, respectively, indicating that even minor reductions in unit production cost can result in major shifts from one production system to another.

2.1 Extensive systems

Extensive aquaculture in Asia is practised in several ways. In all countries considered here, large areas are devoted to extensive earthen pond aquaculture, primarily for finfish and shrimp culture. By definition, external feeds are not applied in extensive systems, but more often than not organic and inorganic fertilizers are applied to augment natural food production in the systems.

2.2 Semi-intensive systems

Asian aquaculture is dominated by semi-intensive freshwater, earthen pond culture systems. In these systems natural productivity is enhanced with fertilizers and the fish or shrimp are provided with supplemental feeds. Feeds are mostly farm-made or made according to farmer specifications by local feed processing plants. For example, in India and Bangladesh almost all inland finfish production is semi-intensive and is based on farm-made feeds. There is an increasing trend in some Asian countries for small-scale, commercial feed manufacturers to produce relatively large quantities of feeds, for a particular species and hence supply the demands within a region. Good examples are the pangasiid feed producers in the Mekong delta in Viet Nam (Hung, Truc and Huy, 2007). These feeds are not necessarily nutritionally wholesome and indeed need not be so.

2.3 Intensive systems

Intensive aquaculture practices in Asia are by and large restricted to shrimp culture, inland and marine finfish cage culture, as well as freshwater culture of some high value species such as eels in China. In intensive systems the cultured stock has to be provided with a complete feed that meets all the nutritional requirements of the species. Such feeds are species specific and in most culture practices will account for 40 to 60 percent of recurrent production costs.

3. FERTILIZER USAGE IN ASIAN AQUACULTURE

There is a long history of organic and inorganic fertilizer use in pond culture of filter feeding finfish species in Asia. The dynamics of fertilizer use and its efficacy in aquaculture is fairly well understood (Hepher, 1988; New, Tacon and Csavas, 1994). In extensive systems fertilizers are often the only input and in semi-intensive systems fertilizer may be regularly and or infrequently applied. Culture systems in which fertilizer is the only input are more often than not small-scale, single pond operations, except perhaps milk fish culture operations in which even large operations use fertilizers to induce the growth of “lab lab”.

Almost all extensive and the majority of semi-intensive aquaculture operations in Asia, with minor exceptions, are dependent on the use of fertilizer and organic manures. Fertilizer and manure usage in aquaculture varies considerably among Asian countries (Table 4). In general, the use of fresh manure is preferred over the application of dry manure. This is because nutrient delivery from wet manure is faster and more efficient. In India and Bangladesh cattle and buffalo manure is extensively used in

TABLE 4
Fertilizer use/availability (2003-04) in some Asian countries

Country/species	Culture period (days)	Yield (kg/ha/year)	Fertilizer use (kg or tonnes/ha/year)		Total usage		Projected requirement (2020)
			Organic	Inorganic	Organic	Inorganic	
Bangladesh							
Shrimp spp.*	100–120	200–400	BDT 200**		Solid biodegradable from market waste etc are also used		
India							
Freshwater finfish (Indian major and Chinese carps)	Variable	Variable; >2 000	20 tonnes (cattle dung and poultry manure)	Nitrogen fertilizer 200 kg; phosphate fertilizer 200 kg	100 million tonnes (cattle dung and poultry manure)	Nitrogen fertilizer 100 000 tonnes; phosphate fertilizer 100 000 tonnes	Organic manure 190.15 million tonnes; nitrogen fertilizer 190 000 tonnes; phosphate fertilizer 190 000 tonnes
Freshwater prawn	NA	860 (40–1 180)	2 500 kg (cattle dung and poultry manure)	Nitrogen fertilizer 45 kg; phosphate fertilizer 45 kg	86 600 tonnes (cattle dung and poultry manure)	Nitrogen fertilizer 1 600 tonnes; phosphate fertilizer 1 600 tonnes	Organic manure 164 500 tonnes; nitrogen fertilizer 3 050 tonnes; phosphate fertilizer 3 050 tonnes
Shrimp	NA	730 (460–1 890)	1 250 kg	Nitrogen fertilizer 15 kg; phosphates 10 kg	125 000 tonnes	Nitrogen fertilizer 1 500 tonnes; phosphate fertilizer 1 000 tonnes	Organic manure 187 500 tonnes; nitrogen fertilizer 2 250 tonnes; phosphate fertilizer 1 500 tonnes
Indonesia							
Finfish (freshwater)	NA	Variable	118 kg	29 kg	19 600 tonnes	7 600 tonnes	
Shrimp (brackish water)	NA	Variable	22 kg	13 kg			
Philippines							
All fish species			2 000 kg	670 kg	489 998 tonnes	190 930 tonnes	Projected requirement will remain same for the next 10 years

*Extensive shrimp aquaculture in Bangladesh is primarily dependent on natural recruitment of shrimp post-larvae.**Quantitative information on fertilizer use for Bangladesh is not available, although farmers spend an average of 200 Bangladesh taka (BDT) per ha per year (US$1.00 = BDT 65.00)

Source: data for Bangladesh, India, Indonesia and Philippines were obtained respectively from Barman and Karim (2007); Ayyappan and Ahamad Ali (2007); Nur (2007); and Sumagaysay-Chavoso (2007) and personal observations.

aquaculture. With the increasing industrialisation of poultry production in most Asian countries, in the last ten to fifteen years, poultry manure has become readily available for use in aquaculture. In the Philippines poultry manure, which ranges in price from US$16.36 to 21.82/tonne, is preferred over other organic fertilizers. Other livestock manure, mudpress (agricultural waste from sugar mills) and rice bran are also used to enhance natural pond productivity but to a much lesser extent. In most countries, fish farmers usually only apply organic fertilizers during pond preparation, although some also apply fertilizers during the rearing period to maintain the growth of phyto- and zooplankton.

The availability of manure, particularly in rural areas has continued to sustain carp culture practices in many countries, and milk fish culture in the Philippines in particular. Improved manure and system management has contributed significantly towards the growth of the carp and milkfish sectors and indirectly has made farmers independent of commercial feeds. In Viet Nam, the use of fertilizers and manure in aquaculture is less common than in other Asian countries and is often confined to the nursery stages when juvenile fish generally perform better on natural food organisms. On the other hand, sewage cum fish culture in urban areas in Viet Nam is popular and encouraged. In the Philippines, there is a greater dependence on inorganic fertilizers in comparison to most other countries. In some countries there are increasing bio-security concerns with regard to the use of animal manure, especially in shrimp culture in Indonesia.

4. AQUAFEEDS

4.1 General considerations

It is difficult, if not impossible, to differentiate accurately between industrial aquafeed production and total animal feed production. This is because the same ingredients are often used for aqua- or other animal feeds and similar industrial production processes. However, only a small proportion of feed production plants in Asia is dedicated aquafeed manufacturers and the bulk of feeds used in Asian aquaculture are non-industrial feeds and hence estimates can be made of total aquafeed production and consumption.

China and India are among the world's top ten animal feed producers, accounting for 11.9 percent (72.7 million tonnes) and 1.6 percent (9.6 million tonnes) respectively of global industrial animal feed production (Gill, 2006). As will become apparent later, only a very small proportion of the industrially produced feeds in both of these countries, and Asia in general, are used in aquaculture. For example, aquaculture in India used 0.24 millon tonnes of industrial feed in 2003 amounting to only 3.7 percent of the total aquafeed of 6.4 million tonnes (Victor Suresh, pers. comm.).

4.2 Types of aquafeeds

Asian aquafeeds can be broadly divided into four categories. The potential of each of these feed types in relation to production/yield is shown in Figure 7.

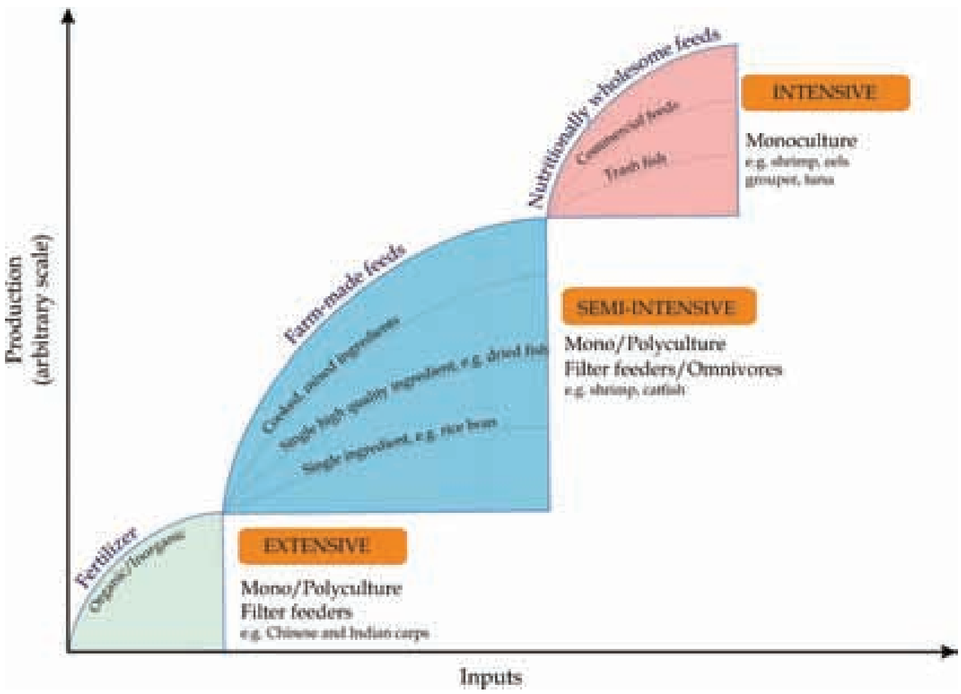
1. Materials and or ingredients of plant origin that are used singly or in combination with others (of plant or animal origin) but with little or no processing. Such feeds are mostly used at the lower end of the semi-intensive culture spectrum, for example in home ponds. The feeds/ingredients vary in quality and nutrient content, e.g. rice bran of rather limited nutritional value and/or mixed with dried fish of high nutritional value.
2. Materials of animal origin, primarily trash fish that is used singly or in combination with others but with little or no processing. Such feeds are mostly used at the upper end of semi-intensive to intensive culture practices and mainly in marine fish culture, e.g. grouper (*Epinephelus* spp.), Asian seabass (*Lates calcarifer*) and cobia (*Rachycentron canadum*).
3. Mixtures of ingredients that are subjected to some form of processing (simple grinding, mixing and cooking resulting in a moist dough or in simple pellets).

Processing is done on farm or in small processing plants, according to the specifications of the farmer. Collectively these feeds are designated as farm-made feeds, and often are the main stay in semi-intensive aquaculture. In the literature they are also commonly referred to as supplementary feeds (De Silva, 1994).

4. Feeds that are manufactured by industrial feed milling plants that are distributed and sold using conventional market chains. Such feeds are expected to fulfil all the nutrient requirements of the cultured species and are mostly used in intensive practices, often by relatively large-scale aquaculture operations. The ingredient composition and all aspects pertaining to feed formulation and manufacturing processes are normally based on research findings and farmers normally do not make any input into ingredient selection and or feed formulations. These feeds are sold under different trade names, generally in 20–25 kg bags and are available for post-larval and shrimp grow-out, tilapia fingerlings and grow-out, common carp, eels, seabass and so forth. The nutrient specifications (percent moisture and protein, lipid, ash, energy content and certain manufacturers will also provide percent nitrogen free extract and fibre content data) as well as the pellet size are indicated on the packaging.

Irrespective of the feed category the majority of the ingredients used in the feeds, particularly in categories (iii) and (iv) are fairly common ingredients. The key ingredients, fishmeal, soybean meal, various oilseed cakes are also used in the production of other animal feeds and hence aquaculture is a direct competitor with other animal husbandry practices. For Asia as a whole the situation is further exacerbated as its contribution to the world supply of these three principal ingredients is minimal in comparison to the proportion that is used by the regional animal feed industry (Figure 6). For example, while Asia produces only 17 percent it consumes 47 percent of the global fishmeal supply.

FIGURE 7
A schematic representation of the effectiveness of fertilizers and different feed types on aquaculture production



4.3 Current usage

A conservative estimate of current aquafeed use in Asia, based on data provided for the target countries, is 19.3 and 10.3 million tonnes of farm-made and commercial feeds, respectively (Tables 5 and 6). It is likely that the consumption of farm-made feeds is significantly underestimated in view of the difficulties in accurately assessing feed use. For example, feed usage in back yard pond culture, which is widespread throughput the region, is rarely accounted for. Also, some countries with limited aquaculture activities have not been taken into account in the above estimates. For example, Hong Kong used 9 600 tonnes of trash fish in 2002 in its relatively small mariculture sector (Chau and Sadovy, 2005), and Sri Lanka used 4 104 tonnes of shrimp feed in 2004 (Weerakoon, pers. comm.).

Based on the above feed use estimates and assuming, rather conservatively that farm-made and commercial feeds have food conversion ratios of 2.0 and 1.3:1, respectively, the total estimated feed use is expected to yield 17.6 million tonnes of finfish and crustaceans. However, the recorded production for 2003 was 24.04 million tonnes (marine finfish = 531 556 tonnes, freshwater finfish = 21 146 200 tonnes and crustaceans = 2 361 055 tonnes), a difference of nearly 6.5 million tonnes. The question therefore, arises whether feed usage is grossly under-represented and/or that the 6.5 million tonne difference is accounted for by extensive practices, although this is highly unlikely. Unfortunately, data pertaining to production in relation to feed use in the different countries are not available and are difficult to collate, except of course for the use of commercial feeds in some practices (Abery *et al*., 2005). However, such data may be very useful in evaluating the efficacy of feed types, which in turn would be of use in bringing about improvements, especially in the case of farm-made feeds that are extensively used in some countries in the region, e.g. India and Viet Nam.

4.4 Aquafeed projections

In Tables 5 and 6 an attempt is made to predict future feed use in the target countries. The total estimates for farm-made and commercial feeds by 2013 are 30.7 million and 22.2 million tonnes, respectively (Figure 8). These predicted values represent increases of 60 and 107 percent for farm-made and commercial feed use, respectively from current levels. For both groups of feeds the highest demand will be from China. Even

FIGURE 8
Current and predicted use of farm-made and commercial feeds in Asia and projected percent increase

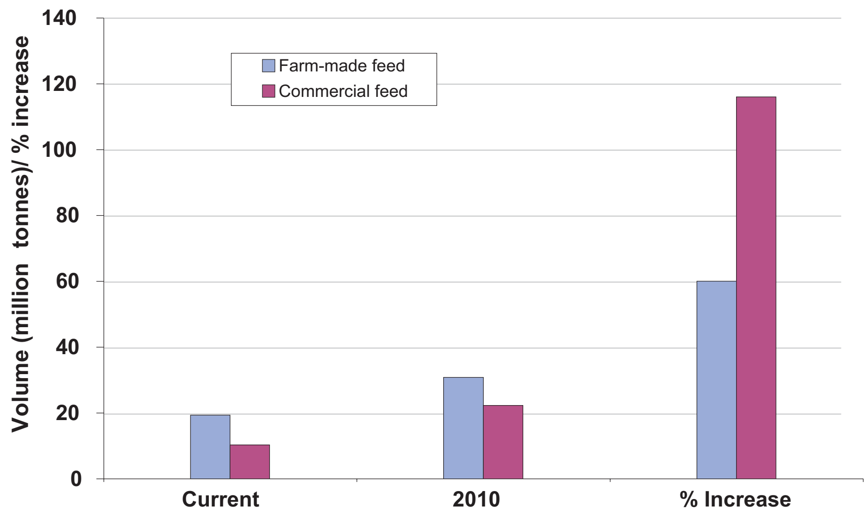


TABLE 5

Current and projected use (tonnes) of single ingredient and farm-made feeds in aquaculture in selected Asian countries

Feeds	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam
Current use							
Finfish	50 000	10 350 000	6 144 947[a]	223 850			500 000
Shrimp	20 000	530 000	~20 000[b]	42 000			
Others				10 000			
Total	70 000	10 880 000	6 164 947	275 850	384 896	762 173[c]	800 000
Projected needs: 2013							
Finfish		13 056 000[d]	7 994 431[e]		828 088		
Shrimp		636 000[d]	276 134				1 500 000
Trash fish		4 000 000					1 000 000
Total	91 000[e]	17 692 000	8 270 565	358 605[e]	828 088[e]	990 824[e]	2 500 000

[a]Rice and wheat bran, oilseed cakes, marine ingredients, others; [b]Fishmeal, squid meal, shrimp meal, mantis shrimp meal, soybean meal, flour, fish oil, lecithin, binders; [c]including trash fish used in diets for seabass and grouper; [d]Based on a 20 percent increase of current usage; [e]Based on a 30 percent increase on current use. Note that in Viet Nam, an estimated 300 000 tonnes of trash fish is used in aquafeeds. Predictions for the increase in shrimp production in India and for finfish and shrimp production and trash fish usage in Viet Nam were made on estimated increases in production volume, and using reasonable FCRs. Calculations were done using 2003 data to ensure consistency between different countries.

Source: Country reviews and personal communications with the authors.

TABLE 6

Number of aquafeed mills operating in selected Asian countries, current and projected production and the major ingredients used (tonnes). Please note that the projections for India are for the year 2020 and the others for 2013

Mills/production	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam
Number							
Fish	-	-	1	-	-	12	13
Shrimp	-	-	28	-	-	34	23
Fish & shrimp	14	360	-	20	78	14	-
Production							
Current							
Fishmeal	NA	1 500 000	48 000[1]	34 485	30 630	248 500	62 500
Soybean meal	NA	2 340 000	33 000	4 523	55 437	145 950	100 000
Corn/wheat	NA	1 550 000	30 000	24 310	NA	78 750	NA
Total	60 000	7 800 000	238 883	490 000	204 396	822 500	696 000
Projected							
Fishmeal	NA	4 050 000	133 147[1]	70 000	105 905	NA	NA
Soybean meal	NA	4 800 000	67 650	15 000	179 146	NA	NA
Corn/wheat	NA	3 004 000	61 500	50 000	297 334	NA	NA
Total	NA	16 000 000	347 500	1 000 000	658 313	2 736 336	1 500 000

[1] Also includes shrimp meal, mantis shrimp meal; NA= data not available or insufficient data available to make predictions. Calculations were done using 2003 data to ensure consistency between different countries.

Source: Country reviews and personal communications with the authors.

in those Asian countries where aquaculture is a relatively minor industry the demand for aquafeeds is expected to increase three to four fold by 2013. For example, in Sri Lanka that has a small aquaculture industry it is projected that feed usage will increase three fold to 12 400 tonnes by 2010 (Weerakoon, pers. comm.). Moreover, Malaysia has adopted a suite of aggressive aquaculture development strategies (Malaysian Ninth Five Year Plan, 2006 to 2010) and envisages to increase aquaculture production from 150 000 tonnes (current) to 600 000 tonnes by the year 2010. Obviously such increases in production (approximately 20 percent per year) have to go hand in hand with feed availability.

4.5 Ingredients used in aquafeeds

As pointed out previously, the key ingredients used in aquafeeds, particularly those used in commercial feeds, are common to those used in terrestrial animal feeds. Consequently, there will be higher levels of competition for these ingredients in the global market, in particular for ingredients such as fishmeal, fish oil, soybean meal and vitamin and mineral pre-mixes. The advantage, if any, in favour of aquafeeds is that aquaculture practices in Asia are predominantly extensive and semi-intensive and for many more years to come will be using farm-made feeds. These feeds allow for the incorporation of a much greater variety of ingredients. Moreover many of these ingredients directly and or indirectly act as nutrient sources that augment natural food production in ponds. These issues have been dealt with in detail previously (De Silva, 1994; Wood *et al*., 1992). The study by Wood (op cit.) raised the question of the value of conventional nutritional wisdom in relation to aquaculture in the tropics and suggested that the provision of nutritionally complete diets in tropical systems may not always be needed.

Ingredients used in aquafeeds are either of plant or of animal origin. Generally, the plant products are less costly and also have the advantage of being relatively easily accessible and available, baring a few exceptions and tend to be the mainstay of farm-made feeds.

4.5.1 Plant and agricultural by-products used in aquafeeds

A large variety of plant by-products are used in the production of aquafeeds, predominantly for the extensive and semi-intensive aquaculture feed categories (i) and (ii) (see above). The exceptions are soybean meal and wheat flour that are also used in feed categories (iii) and (iv). Soybean meal is one of the most widely used ingredients in all types of feeds. This is because of its favourable nutritional composition and digestibility, its availability and long shelf life.

The most commonly used plant based ingredients in Asian aquafeeds and their availability are summarized in Table 7. The data is by no means exhaustive but provides an indication of the main ingredients that are used in the seven target countries. The majority of these ingredients are either used singly or in various combinations. However, the extent of use of plant based agricultural by-products, despite the fact that some have a high protein content, in aquafeeds is limited. Foremost among factors that discourage the use of agricultural plant based by-products are:

- unfavourable amino acid balance;
- inferior digestibility;
- presence of anti-nutritional factors; and
- localised and seasonal availability.

The first three of the above factors have been addressed extensively (Tacon, 1987; De Silva and Anderson, 1995; Hertrampf and Pascual, 2000; and contributions to this volume). Despite extensive research the incorporation of plant based by-products in aquafeeds is limited. This issue is discussed in greater detail later.

In general, Asian aquaculture relies heavily on agricultural produce and by-products. Consequently, there is increasing competition from alternative users and this has led to substantial price increases. Availability, seasonality and the demand for plant based agricultural by-products varies appreciably between countries.

Throughout the region, there is little data on competitive uses of agricultural by-products in animal husbandry and other forms of agriculture. The lack of this crucial information is largely due to the difficulties of data collation and the absence of interdisciplinary approaches to natural resource use patterns in all farming systems. Aquaculture, as the newly emerged farming system, on the present scale of activities, will in all probability have to take the lead in assessing comparative resource use, particularly in rural areas where the issue is pivotal.

TABLE 7
Commonly available and potentially useful agricultural by-products and plants used in Asian aquafeeds. Where available, estimates of availability is in thousand tonnes/year. Figures in parentheses indicate current estimated usage in aquafeeds

Ingredient	Bangladesh	China	India*	Indonesia	Philippines**	Thailand	Viet Nam
Plants/leaf meals							
Azolla				+			
Cassava				+	201	+	
Duckweed	+					+	+
Leucaena				+	0.6		
Spirulina			+			+	
Water hyacinth	+					+	+
Water velvet							
Brans							
Black gram	+						+
Corn					1 137	4 000 (79)	
Lentil	+						
Rice	1 254	+	3 000–3 500	+	1 450	+	3 350 (300–500)
Wheat	+	+	2 000–2 500	+		+	+
Oil cakes							
Coconut	86		140–160	+	704 (9.6)	+	
Cottonseed		4 000–5 000	750–800				
Groundnut	30	14 000–15 000	8 000–8 500			+	
Linseed	+		100				
Mustard/rapeseed	234		5 000–5 800				
Rapeseed		5 000 (4 000)					
Sesame	+		450–500				
Soybean meal/ cake		15 500–17 550	5 000–5 500	+	(55.4)	298 (141)	1 185 (80–132)
Sunflower		+	800–1 000				
Others							
Corn gluten							
Corn meal	+	+	+	+	3 735	+	+
Molasses		+	+			+	
Pulses			+			+	
Rice (broken)	+	+	+			399	2 010
Sorghum			7 500–8 000	+			
Tapioca/cassava			5 600–6 000	+	1 040	+	5 230 (30–45)
Wheat flour	+	+	+			+	+
Wheat gluten		+				+	

*Current usage in aquaculture: rice and wheat bran 85.8 thousand tonnes, oil cakes/meals 39.0 thousand tonnes, marine ingredients 75.5 thousand tonnes, cereal 30.0 thousand tonnes, others 2.6 thousand tonnes; **current usage in aquaculture: rice bran/corn bran/wheat flour 94 thousand tonnes.

Source: data for Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam were obtained respectively from Barman and Karim (2007); Weimin and Mengqing (2007); Ayyappan and Ahamad Ali (2007); Nur (2007); Sumagaysay-Chavoso (2007); Thongrod (2007); and Hung and Huy (2007)

4.5.2 Animal industry by-products used in aquafeeds

a) The animal husbandry industry

Asia, particularly China, India and Thailand, has considerably large animal husbandry industries, in particular poultry and pig industries. The processing waste resulting from these industries are substantial. Overall, the use of animal husbandry by-products, such as bone meal, blood meal and feather meal, is not adequately organized such that the use of many of these highly nutritious materials, even though there are no legal restrictions (e.g. such as in the use of bone meal in Europe), is rather sporadic and isolated. The approximate availability of potentially useful animal industry by-products for aquafeeds is presented in Table 8.

In most instances, animal industry by-products are mainly used for farm-made feeds and are rarely incorporated into commercial feeds.

b) Fishing industry by-products

The nutrient composition of fish by-products, from the surimi industry, fish canning industries, filleting plants and the like has been shown to be very close to that of fishmeal (Gunasekera *et al.*, 2002). This clearly indicates the potential of these resources as a possible replacement for fishmeal in aquafeeds. For example, it has been estimated that India produces some 340 000 tonnes of fish industry waste that is available for aquafeeds.

With one or two exceptions, the only by-product that has been used to any substantial extent in Asian aquafeeds is shrimp processing waste, primarily in the form of shrimp head meal. A recent development in Viet Nam is the use of processing waste from *Pangasius* catfish culture. Viet Nam is the largest producer of pangasiid catfish (*Pangasius hypophthalamus* and *P. bocoutii*) in the region, producing around 300 000 tonnes per annum, which generates approximately 210 000 tonnes of waste (Hung and Huy, 2007; Hung, Truc and Huy, 2007). The bulk of the waste is used for the extraction of oil and for inclusion in farm-made feeds. This is unique and illustrates how aquaculture waste can be used efficiently and effectively. Considering that aquaculture in Asia is often practised in sizeable clusters, the strategy adopted in the Mekong delta should be replicated in areas where there are adequate volumes of waste products. This could result in significant cost savings and employment in a region.

TABLE 8

Commonly available animal industry by-products (thousand tonnes) in several Asian countries. Figures in parentheses indicate current estimated usage in aquafeeds

Ingredient	Country						
	Bangladesh	China	India	Indonesia	Philippines	Thailand	Viet Nam
Blood meal	+	+		+	46.8	+	
Meat and bone meal	+	+	55.2		243.5	+	
Catfish waste							210
Feather meal		+	+		23.0	+	
Fishmeal	+	+	202–208	+	(30.6)	611 (234.5)	248–255 (46.5–62.5)
Fish silage		+					
Krill meal				+			
Nereis meal				+			
Poultry offal			65		45.9	+	
Shrimp meal	+		106	+			
Shrimp head meal			31	+	7.2 (1.7)	+	60–70
Silk worm pupae	+	+	40				
Slaughterhouse waste		+	+			+	
Snail meal				+			
Squid meal		+	19–21			+	
Trash fish		5 316*		+		756* (131.9)	933.2 (176.4–363.4)

Source: data for Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam were obtained respectively from Barman and Karim (2007); Weimin and Mengqing (2007); Ayyappan and Ahamad Ali (2007); Nur (2007); Sumagaysay-Chavoso (2007); Thongrod (2007); and Hung and Huy (2007). *Fung-Smith et al. (2005)

c) Trash fish

Asian finfish mariculture, particularly grouper and cobia farming, is growing rapidly in China, Viet Nam and Indonesia and is largely still dependent on trash fish as a feed. It has been estimated that Viet Nam will use nearly one million tonnes of trash fish and China will require approximately 4 million tonnes of trash fish by 2013 to sustain marine cage culture activities. Trash fish is mainly obtained from commercial marine fisheries although a fair share is also supplied by artisanal fisheries, particularly in Viet Nam. The supply of trash fish in Asia is highly seasonal and dwindling (Edwards, Tuan and Allan, 2004). However, the demand for the commodity by the marine finfish culture sector in many countries is high and increasing. There is a growing concern with regard to the environmental effects of using trash fish in aquaculture. Moreover, its efficacy as an aquafeed is debateable and its preferred use appears in many instances to be based more on farmer perceptions than economic reality. For example, a recent study on grouper cage culture in Viet Nam showed that the average survival, FCR and cost of production using formulated pellets were 62.2 percent, 2.12:1 and US$2.18/kg as opposed to 54.5 percent, 7.38:1 and US$2.58 using trash fish, respectively (Anon., 2006).

There is an urgent need to reduce the dependence of the industry on trash fish in the ensuing years. This can only be achieved through the development of suitable dry, pellet feeds and appropriate on-farm R&D activities to convince farmers of the benefits of being less reliant on trash fish.

4.6 Aquafeed formulations

4.6.1 Farm-made and or "semi-commercial" formulations

As mentioned above, semi-intensive finfish culture is the dominant aquaculture practice in Asia and is primarily dependent on farm-made and/or "semi-commercially" prepared aquafeeds. The formulations of these feeds differ considerably regionally and nationally (Table 9) and are mostly determined by ingredient availability and cost. In general however, a few base ingredients are used and these normally are soybean meal, wheat flour and rice bran, supplemented with fishmeal or with an ingredient that matches the composition of fishmeal as closely as possible. It is however, difficult to generalise as farm-made feeds may be very species specific (Table 10).

Efficacy of farm-made and or "semi-commercial" feeds

Considering that the bulk of aquaculture production in Asia is dependent on farm-made and or "semi-commercial" aquafeeds and the fact that there has been a considerable increase in aquaculture production over the past decade, it is reasonable to conclude that the efficacy of these feeds has contributed substantially to the growth of the sector. However, this fact often goes un-noticed and receives little attention. A possible way to infer the efficacy of these feeds is to consider production levels in different culture systems (Table 11). From these data it is evident that the production levels for a variety of systems are substantial, especially considering the level of inputs and the capital investment. It would be most useful to obtain more detailed data on these aspects and to conduct a comprehensive analysis. This would no doubt provide valuable information to increase production even further. The recent changes in pangasiid culture (see above and Hung, Truc and Huy, 2007) (Figure 9) serves as a good example to illustrate this point. Clearly, many more such focused studies are needed to increase our understanding of farm-made feeds, which can only result in bringing about further improvements in feed efficacy.

TABLE 9

Examples of ingredient composition (arranged in descending order of inclusion level) and other relevant information, where available, for selected farm-made feeds (for grow-out unless otherwise stated) in selected Asian countries

Country/Species	Ingredients	Preparation/ feeding	Cost (US$/kg)	% Protein
Bangladesh				
Carps	MOC, RB/WB	Made into wet balls		
Pangasius (catfish)	RB, MOC, WF, WB, RB, FM, BM	MOC is soaked for 24 h and mixed with other ingredients; made into balls		
Carp and shrimp	MOC, DFM, RB, WF, molasses		0.25	
Shrimp	RB, MOC, WF, molasses			
China (only selected examples are given)				
Tilapia (grow out)	SBM, wheat middling., corn, PBM FM, VO, VMPM	Where needed ingredients are minced and / or ground and mixed and then cooked		28.5
Common carp, crucian carp, tilapia	RSM, SBM, WF, corn, WB, FM, binder		NA	NA
Grass carp, amur bream	RSM, WF, corn, WB, SBM, binder			
Chinese mitten crab	SBM, RSM, FM, WF, WB, shell meal, MIA, others		NA	NA
Giant freshwater prawn	SBM, RSM, WF, FM, WB, shell meal, binder, VMPM		NA	NA
India				
Indian major carps	RB, PC, CSC		0.10	20
Shrimp- made to order	DFM, mantis shrimp, sergestid shrimp, SBM, SWP, MG, WF, GRM, RB, FO		0.45	
Indonesia				
Juvenile grouper	TF, FM, GRM, cassava starch, FO	Moist feed- prepared daily		48
Philippines				
Milkfish	RB, SBM, FM, FO		0.38	26.7
Tilapia	Cassava flour, SBM, FM, CM, RB, VMPM		0.56	28.1
Catfish	SBM, RB, FM, WF, SBO, VMPM		0.40	34.2
Grouper	FM, MBM, BM, SM, SBM, VM, FO, VMPM		1.30	44.0
Mudcrab	MBM, FM, WF, RB, CB, SW		0.78	40.1
Tiger prawn	FM, SBM, SM, WF, RB, SW, FO, SBO, cholesterol, VMPM		0.81	41.7
Thailand				
Walking catfish and tilapia (larvae)	FM, cassava starch, RB, VO, VMPM, binder	Ground, mixed and fed; prepared daily; may use feed bags	0.45	37.5
Walking catfish (grow out)	SMB, dried cassava, coconut meal, CM, FM, FO, VPM		0.24	28
Shrimp, carnivorous marine fish	TF, other ingredients, VMPM	Ground, extruded, cooked; cooked feed cooled; packed and stored in ice; shelf life 1 week	NA	NA
Viet Nam				
Catfish	RB, TF, SBM	Mixed and ground on site		
Grouper	TF	Chopped and fed		

CB- corn bran; CM- coconut meal; CSC- cotton seed cake; DFM- dry fishmeal; FM- fishmeal; FO- fish oil; GRM- groundnut meal; MBM- meat and bone meal; MG- maize gluten; MIA- moult inducing agent; MOC- mustard oil cake; PC- peanut cake; RB- rice bran; RSM- rape seed meal; SM- shrimp meal; SBM- soybean meal; SBO-soybean oil; SW- seaweed; SWP- silk worm pupae; TF- trash fish; VO- vegetable oil; WB- wheat bran; WF- wheat flour, WG- wheat gluten; WM- wheat meal, PBM- poultry by-product meal, VMPM- Vitamin and mineral premix

Source: data for Bangladesh, China, India, Indonesia, the Philippines, Thailand and Viet Nam were obtained respectively from Barman and Karim (2007); Weimin and Mengqing (2007); Ayyappan and Ahamad Ali (2007); Nur (2007); Sumagaysay-Chavoso (2007); Thongrod (2007); and Hung and Huy (2007)

TABLE 10
Different feed formulations for two pangasiid catfish (*Pangasius hypophthalamus* and *P. bocoutii*) in the Mekong Delta

Ingredients	Formulation 1	Formulation 2
Trash fish	20–30%	
Rice bran	50–70%	40–50%
Broken rice	10–20%	-
Soybean meal	-	20–30%
Fish by-products	-	10 –30%
Others (corn, vegetables)	-	20%

Source: Hung, Truc and Huy (2007)

TABLE 11
Production levels using farm-made and or "semi-commercial" aquafeeds in different countries

Country/ Species groups	Type of culture	Production (kg/ha/year)
Bangladesh		
Major carps	Pond/polyculture	2 000–3 000
Shrimp/ carps	Pond	2 800–3 000
India		
Major carps	Pond/polyculture	5 000–8 000
Philippines		
Milkfish	Pond/monoculture	1 500–3 500*
Viet Nam		
Pangasiid catfish	Cage culture	150–200**

*kg/ha/crop; **kg/m^3/crop

Source: data for Bangladesh, India, the Philippines, and Viet Nam were obtained respectively from Barman and Karim (2007); Ayyappan and Ahamad Ali (2007); Sumagaysay-Chavoso (2007); and Hung and Huy (2007)

The future of farm-made feeds

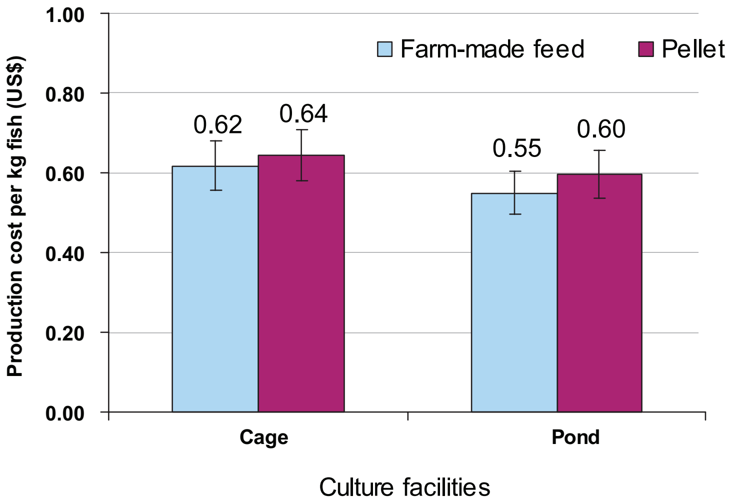
It is important to note that production per unit area has increased over the years with the use of farm-made and or "semi-commercially" aquafeeds. This increase is at least partially attributable to improvements in feed formulations as well as improvements in the processing techniques. As pointed out previously, such improvements as well as the increasing trend to include vitamin and mineral pre-mixes and binders are mostly brought about by farmer interventions and this has led to greater feed utilization efficiency. Over a decade ago, De Silva and Davy (1992) identified the need for a concerted research effort on farm-made feeds. They suggested then that farm-made feeds will continue to constitute the "back-bone" of aquaculture in Asia and those improvements to these feeds could result in very significant production gains. For the following reason this call is made again. Farmers have continued to bring about improvements to feed formulations primarily based on trial and error. If such improvements were to be backed up with focused research then farm-made feeds will make an even greater contribution to the sustainable development of aquaculture in Asia.

Finally, there is an unknown factor in relation to the efficacy of farm-made feeds. It is not known how much of the feed provided is utilized directly as opposed to its indirect "fertilizer" value. The latter may be an important factor that could provide clues for further increasing the efficacy of these feeds, therefore bringing about a saving in ingredient use and costs.

Constraints and needs

As pointed out above, the lack of research has impeded and constrained developments in farm-made and or "semi-commercial" aquafeeds. In addition, there are other local constraints that operate and hinder growth in the sector. Foremost among these, is the availability of key ingredients and access to these on a regular basis. This is primarily a consequence of poor market chains, which in turn may be a reflection

FIGURE 9
Comparison of the efficacy of farm-made versus pellet feeds in pangasiid aquaculture in the Mekong Delta



Source: Hung, Truc and Huy (2007)

of the scant recognition by the authorities of the importance of efficient distribution channels to aquaculture production. The provision of suitable credit, storage facilities and the like, in a given region, may mitigate against some of these factors.

Given that a high proportion of aquafeeds is made by small, semi-commercial feed processors there is an increasing need to provide suitable support for this manufacturing sector. This would facilitate greater efficiency, which would result in overall feed cost reductions and enhance productivity. Most importantly, this sector needs easier access to credit such that they can improve their storage as well as processing facilities. The development of this important feed manufacturing sector would also be greatly facilitated by training extension officers to monitor and provide advice on ingredient selection, feed formulation and processing. This will enhance farmer and processor confidence and stimulate the adoption of new and cost effective formulations.

4.6.2 Commercial formulations

Commercial aquafeed formulations are often considered as "trade secrets" and are not generally available to the public. The bulk of aquafeed production in Asia comprises shrimp feeds. Current regulations require the manufacturer to provide information on the quantity in each container, the type of feed and its gross nutrient composition. Needless to say, quality control measures with respect to food products in Asia are not as stringent as in the developed world, and aquafeeds are no exception in this regard. For example, a recent study has shown that in the majority of feeds the protein content was overestimated, whilst the fibre and the fat content were underestimated (Kader, Hossain and Hasan, 2005). Similarly, poor gonadal recrudescence and the consequent inability to artificially propagate two mahseer species (*Tor tambroides* and *T. douronensis*) in Sarawak, East Malaysia, was attributed to sub-standard (no HUFA) commercial feeds on which these fish were reared (Ingram *et al*., 2005).

4.6.3 The need for regulatory measures

Many of the Asian countries have recently introduced and or are in the process of introducing quality control measures for commercial aquafeeds. However, in most cases such regulations are restricted to the minimum and maximum inclusion levels of the gross nutrients for a particular species or life history stage. In general there are no regulations on heavy metal and or other organic compounds contents that may affect human health. Exporters of aquaculture products have to comply with stringent health and quality control measures and for this reason farmers require more detailed information. Moreover, regulations are effectively quite useless if they are not enforced through a regular monitoring programme.

5. MAJOR TRENDS IN RELATION TO AQUAFEEDS IN ASIAN AQUACULTURE

Although there is a general increase in the use of commercial feeds in most Asian countries this trend is often masked by changes that are occurring in semi-intensive aquaculture. Increasingly, small-scale semi-intensive farmers are mechanizing their farm-made feed processing facilities, mostly through improvisation and adaptation of old machinery meant for other purposes. The other notable trend (see above) is the rapid growth of the "semi-commercial" feed processors, who provide customised formulations on demand and in small, affordable quantities. This trend is most prevalent in Bangladesh and India, with the Philippines following suite. This practice enables the farmer to contain feed costs and hence is in a better position to manage the cash flow of the enterprise. This practice also allows the farmer to test various feed formulations at virtually no extra cost. As referred to above, such farmer initiated trials have contributed substantially to increased production levels. If a system were to be introduced to monitor the composition of the feeds on a regular basis and to link this with the seasonal availability of ingredients then further improvements and cost savings could most certainly be achieved.

During the last decade finfish mariculture has become increasingly dependent on trash fish. This is a major concern and for several reasons is unlikely to be sustainable in the long-term. The reasons include the rapidly dwindling "trash fish" resource (Edwards, Tuan and Allan, 2004), environmental degradation resulting from the use of trash fish and most importantly the growing public perception and awareness that the resource should be used for food instead of an animal feed. There is an urgent need to address this dilemma. The only possible option is for finfish mariculture operators to shift from using trash fish to "semi-commercial" or commercial aquafeeds. To expedite this shift may require the setting up of mariculture demonstration units to convince the practitioners of the benefits of using specifically formulated feeds.

6. ASIAN AQUAFEEDS IN A GLOBAL CONTEXT: ISSUES AND CHALLENGES

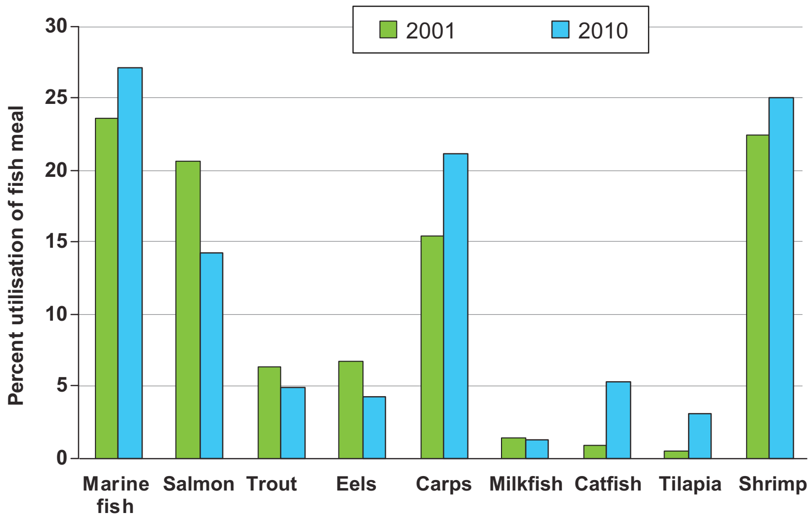
Since the initial coining of the term "the fishmeal trap" and its potential consequences on aquaculture developments (Wijkstrom and New, 1989), much water has "flown under the bridge". Public concern regarding the use of fishmeal and fish oil in aquaculture has taken centre stage and has generated much controversy and debate (Naylor *et al*., 2000). Two facts can be discerned from the controversies:

- Most of the criticisms were aimed at salmonid culture; and
- Many of the issues raised can, to a great extent, be refuted as the data that were used for the analyses are not necessarily fool proof in trying to illustrate the detrimental effects of salmon culture on the environment in a holistic manner.

Similarly, there is increasing public concern about the overall impacts of aquaculture on environmental quality. Needless to say, the onus is on aquaculture, particularly salmonid aquaculture, to defend its position and to clean up its act where necessary. But what does all this mean for Asian aquaculture?

Tacon (2004) estimated that fishmeal usage by 2010 (Figure 10) for carnivorous, temperate fish aquaculture will probably decrease by 10.7 percent to 305 378 tonnes and that fishmeal use for tropical fish aquaculture (carps, tilapia, milk fish, Chinese bream, etc), particularly in Asia, will increase by 7 percent to 713 500 tonnes. It is suggested that the reduction in fishmeal usage by carnivorous species aquaculture will be primarily achieved through decreases in the dietary protein content of feeds and therefore the level of fishmeal inclusion. By 2010, Asia is also expected to account for another 25 percent of global fishmeal usage for shrimp feeds and that this will amount to 713 500 tonnes. Based on these estimates Asia will use a minimum of 50 percent of global fishmeal production. Tacon (2004) also projected that "marine species" aquaculture, by 2010, will use 27.1 percent of the global fishmeal supply. Given that Asian marine finfish culture is currently based largely on trash fish it is difficult to estimate what proportion of this will be consumed in Asia.

FIGURE 10
Current and projected commercial feed usage by different categories of cultured finfish groups and shrimp



Source: Tacon (2004)

On the assumption that Tacon's (2004) projections are reasonable it is clear that the aquafeed industry in Asia, in the foreseeable future, will have to find ways and means of reducing fishmeal usage. The biggest challenge lies in the reduction of fishmeal usage in aquafeeds for omnivorous species.

7. POLICY DEVELOPMENTS

It is difficult to pin-point significant policy developments that have facilitated aquafeed production in Asia. One reason for this may be that the aquafeed sector is too small to have gained recognition and attention by government planners, except perhaps in Viet Nam, where the sector is increasingly recognized as a significant contributor to foreign exchange earnings and national GDP.

The aquafeed sector in most Asian countries is dependent on a number of imported ingredients, most notably fishmeal and additives and will continue to be so well into the foreseeable future. Perhaps one of the most important policy developments that should be considered is the provision of appropriate tax incentives to small-scale feed processors and the reduction and/or abolition of import duties on selected ingredients. It is common knowledge that some of the larger aquafeed companies in the major aquaculture countries in the region are recording large profit margins, while the small-scale processors rarely make sufficient profits to enable expansion, resulting in decreasing competitiveness in the market place. This is not a healthy trend for the sector in general. It may be worthwhile for countries to consider levying a fee on unit tonnage production by manufactures whose capacity and market share exceeds a certain proportion. This revenue could be used for research and development activities. However, such steps have to be in conformity with other feed manufacturing industries in the primary production sector and have to be assessed and determined on a country wise basis.

8. FUTURE NEEDS

The foremost future task of the aquafeed industry in Asia will be to reduce its dependence on trash fish and fishmeal (and oil). Clearly, there will have to be a shift from trash fish usage to farm-made, "semi-commercial" feeds and or commercial feeds.

Such changes will have to involve a fair quantum of research and development work, which will have to go hand in hand with extension services to facilitate the change. To reduce the use of fishmeal in commercial feeds will be more difficult and can only be affected by the industry. There has been on-going research on fishmeal substitution for almost all species that are cultured in Asia. Some of the results are encouraging but findings are rarely translated into commercial practice. The reasons for this are not clear but a remedy has to be found. Perhaps feed manufacturers do not perceive the need to change because of their current market share and profit margins. Alternatively, there may be genuine practical problems in translating the research results into commercial practise. Irrespective of the reason or reasons there is a need for urgent dialogue as the sector as a whole faces serious challenges and these can only be wholly or partially solved through cooperation and involvement by all.

It is most likely that the current regional growth of the aquaculture sector will be sustained largely by improvements in farm-made and or "semi-commercial" feed formulation and processing. It was previously concluded that most of the advances in the efficacy of these feed can be attributed to farmers. To meet the needs and future demands of the aquaculture sector it is imperative to launch a concerted research effort on farm-made feeds and in particular on ingredient quality, seasonal variability, marketing and storage, improvements in processing technology, feed formulation and the most effective way of presenting the feeds. As most semi-intensive aquaculture practices and their ancillary industries occur in clusters findings will be easily disseminated and adopted by the practitioners.

More and more farm-made feeds are likely to be processed by dedicated small-scale feed processors in future and feed "manufacturing/ processing" chains are likely to develop in most clusters. To facilitate this process will require the engagement of suitable qualified aquaculture extension workers.

There is a substantial information on the nutritional requirements of almost all major fish and crustacean species cultured in Asia, as well as information on apparent digestibilities, fishmeal substitution and other related aspects. The synoptic collation of this information for each species will help to eliminate duplication of research efforts and will provide useful information to bring about improved feed formulations.

The commercial aquafeed sector is not without its own problems, particularly the smaller manufacturers and the specialized feed mills that manufacture shrimp feeds. The highly seasonal nature of shrimp production forces many of the manufacturers to operate far below their capacity, often making such operations barely viable. However, these manufacturers are often located in areas where culture practices are clustered, thereby reducing transport and storage costs. It is important that this sector is provided with appropriate incentives to remain economically viable.

9. CONCLUSIONS

Globally and in Asia, aquaculture faces a challenging decade ahead, particularly because of the increasing competition for primary resources and growing public concern and perceptions about the sector. Added to all this are the increasingly stringent quality control measures imposed by exporters that may restrict aquaculture practices in future. Asian aquaculture has a predominantly rural, small-holder base and is likely to continue that way, except perhaps with regard to shrimp culture. This foundation is, in a way, advantageous for it to retain its momentum and sustainability.

However, the momentum of Asian aquaculture can only be sustained if feed inputs do not become a limiting factor, and if further improvements are made to feed quality and availability at reasonable prices. In both semi-intensive and intensive aquaculture feeds often account for 40 to 60 percent of recurrent costs, and as profit margins in most aquaculture practices are relatively narrow, it is imperative that feeds are available at a reasonable price.

Asian aquaculture is dominated by semi-intensive production and the bulk of production is dependent on farm-made and/or "semi-commercial" aquafeeds. Farmer ingenuity has led to significant improvements in feed formulations and processing. To further improve these feeds, which are the key to sustaining the sector and its momentum, there is a need for a concerted research and development effort in all Asian countries, backed up by improved extension services.

There has been a gradual increase in the use of commercial aquafeeds over the years in Asian aquaculture and this is principally attributable to the growth in shrimp culture, which has almost reached saturation levels in most countries. There is evidence to suggest that some aquafeeds do not conform to their specified formulations and hence there is a need for more stringent regulatory measures. Furthermore, throughout Asia there is a need for the commercial feed industry to be more mindful of research results, particularly with respect to fishmeal replacement studies and hence there is a great need for improved dialogue between research and industry.

The Asian finfish mariculture sector has to rapidly reduce its dependence on trash fish. Farmers must be encouraged to switch to commercial or other appropriate farm-made feeds. This may require regional government support. If this switch does not occur then finfish mariculture in Asia is doomed.

The commercial aquafeed sector in Asia is dependent on fishmeal (and fish oil) imports. Furthermore, Asian aquaculture is not immune to global changes and controversies that are emerging in regard to these key ingredients. Such changes tend to influence policy makers at national and international level. Consequently the Asian aquaculture industry needs to be proactive through suitable remedial and or mitigating measures. It is in this context and the fact that the bulk of Asian aquaculture production occurs in semi-intensive systems that it may be advantageous for the sector to concentrate its efforts on improving farm-made and or "semi-commercial" aquafeeds and developing more appropriate feeding practices.

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Feeds and fertilizers for sustainable aquaculture development: a regional review for Latin America

A. Flores-Nava
Universidad Marista de Mérida
AP 151-CORDEMEX, Mérida, Yucatán, 97300
México

Flores-Nava, A. 2007. Feeds and fertilizers for sustainable aquaculture development: a regional review for Latin America. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 49–75.

SUMMARY

In 2004 total aquaculture production in Latin America (South and Central America and the Caribbean) was 1.32 million tonnes. This review focuses on six countries (Brazil, Chile, Cuba, Ecuador, Mexico and the Bolivarian Republic of Venezuela), which collectively accounted for 86.8 percent of the total production. The balance is contributed by 29 other countries. Chile is the largest producer country contributing 51 percent to total production.

Given the semi-intensive and intensive nature of most production systems, there is an almost exclusive dependence on manufactured feeds throughout the region. Although fertilizers, chiefly inorganic, are still widely used there is a gradual decline in organic and inorganic fertilizer use as farmers are shifting to more intensive systems.

High quality aquafeeds are produced for at least 9 species, in more than 200 feed mills throughout the region. Sinking as well as extruded floating pellets are available in a wide range of sizes. Protein levels, depending on the species, range from 25 to 42 percent. In 2003 Chile produced 750 000 tonnes of high protein feeds for Atlantic salmon and is the largest producer in the region. Feeds for marine shrimp and tilapia follow in terms of volume, and these are produced and traded in a number of countries in the region.

Despite the regions high biodiversity and availability of agricultural and industrial by-products little has been done to gradually replace fishmeal, fish oil and soybean meal. The price of these feed commodities is increasing due to rising demand and climate induced erratic supplies, hence feed prices will continue to escalate.

The Latin American aquafeed industry maintains close links with farmers and provides them with technical assistance and credit. This relationship influences the feeding regimes and practices, which are practically the same throughout the region. Farmers are increasingly forming clusters, which allow them to use economies of scale, implement quality assurance strategies and strengthen their capacity to comply with international food safety requirements. As a consequence traceability and food safety programmes are rapidly being adopted by the industry and governments are gradually following suite.

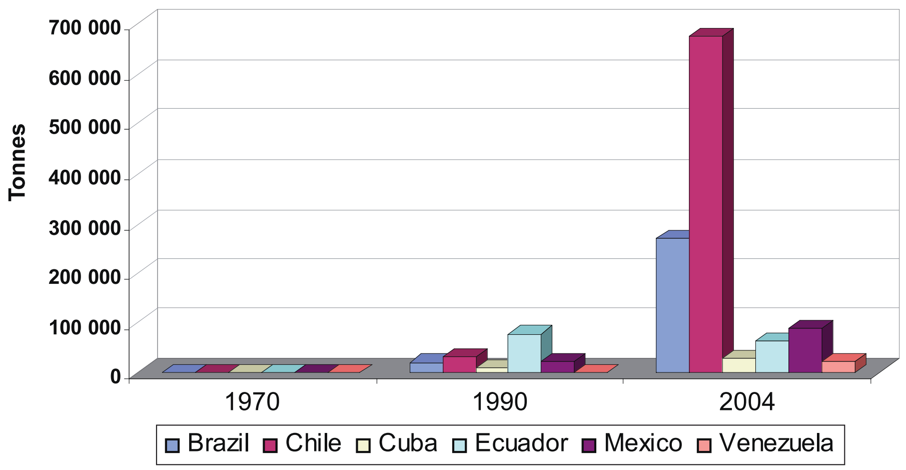
In response to disease outbreaks and national environmental regulations, heterotrophic systems are gradually becoming common in the region, especially in shrimp and tilapia farms. This presents opportunities for reducing aquaculture discharges into the environment and improved feed utilization.

Small-scale aquaculture and agriculture farmers that wish to integrate aquaculture into their traditional agricultural systems are constrained by the high cost of formulated feeds and the lack of basic knowledge on the use of locally available ingredients for the production of low cost, farm-made feeds. This could make a significant contribution to the economic sustainability of rural aquaculture, thus benefiting large sectors of the population.

1. GENERAL OVERVIEW OF AQUACULTURE IN LATIN AMERICA

In 2004, the estimated total aquaculture production (excluding seaweeds and aquatic plants) for the Latin American region (South and Central America and the Caribbean) was 1.32 million tonnes, representing 2.3 percent of the global aquaculture production (FAO, 2006a), showing an overall average growth of 21.3 percent per year during the period 1950–2004 (FAO, 2006b). Throughout the region the aquaculture sector has been growing rapidly in the last decade. Since 1994 total production for the region has increased by 73 percent. This review focuses on the six countries (Figure 1), which on a combined basis account for 86.8 percent of the regions total production.

FIGURE 1
Aquaculture production statistics for the six most important producer countries in Latin America for 1970, 1990 and 2004



Source: FAO (2006a)

The six countries included in this review are Brazil, Chile, Cuba, Ecuador, Mexico and Bolivarian Republic of Venezuela. In 2004, Chile contributed 51.1 percent of the regional total, based chiefly on the production of Atlantic salmon (*Salmo salar*), followed by Brazil (20.4 percent) with a more diversified industry in which Pacific white shrimp (*Litopenaeus vannamei*) is the most important and with increasing production levels of tilapia, carp and native finfish such as the tambaqui (*Colossoma macropomum*) and pacú (*Piaractus mesopotamicus*). Mexico, in which marine shrimp and tilapia are the most important species, is the third largest producer (6.7 percent), followed by Ecuador (4.8 percent), which is the regions top exporter of shrimp (Table 1).

While the review only considers six countries to illustrate among other aspects the geographical diversity of aquaculture in the region, the sector is also well developed in several other countries (Table 2). The expansion of the aquaculture industry within the region has been stimulated by a steady increase in foreign investment, as well as local agricultural diversification and expansion of international markets for fishery products. Overall this has resulted in a rapidly growing, export-orientated sector.

Apart from Chile, where the industry is based on temperate species, all other countries of the region practice aquaculture of tropical and sub-tropical species. Since the early 1970’s there has been a general and distinct trend towards greater intensification, from extensive to intensive systems. This has stimulated the development of support industries and services such as producers and suppliers of feeds, fertilizers, consulting services, equipment, drugs, etc.

TABLE 1
Aquaculture production (tonnes) and value (thousand US$) of the top ten aquaculture producing countries of Latin America in 2004

Country	Volume (tonnes)	% of regional production	Value (thousand US$)	% of regional value
Chile	674 979	51.1	2 814 837	53.6
Brazil	269 699	20.4	965 628	18.4
Mexico	89 037	6.7	291 329	5.5
Ecuador	63 579	4.8	292 077	5.6
Colombia	60 072	4.5	277 036	5.3
Cuba	27 562	2.1	29 434	0.6
Costa Rica	24 708	1.9	80 218	1.5
Honduras	22 520	1.7	114 942	2.2
Bolivarian Republic of Venezuela	22 210	1.7	65 785	1.3
Peru	22 199	1.7	130 555	2.5

Source: FAO (2006a)

TABLE 2
The range of aquaculture production volumes (2004) in Latin American countries not included in this review

Production (tonnes)	Country
>60 000	Colombia
20 000–-30 000	Costa Rica
	Honduras
	Peru
10 000–12 000	Belize
4 000–8 000	Guatemala
	Jamaica
	Nicaragua
	Panama
1 000–3 000	Dominican Republic
	El Salvador
	Paraguay
400–1 000	Bolivia
	Guyana
	Puerto Rica

Source: FAO (2006a)

Contrary to many Asian and African countries (see De Silva and Hasan, 2007 and also Hecht, 2007), the bulk of the aquaculture industry in Latin America is export-orientated. However, price-related market constraints have recently prompted shrimp producers to focus on local markets. This has been greatly facilitated in countries such as Brazil and Mexico where economic stability has improved the purchasing power of a growing middle class.

The Chilean salmon industry is expected to keep pace with the rising global demand for the next decade. However, the number of salmon farming companies is likely to remain unchanged as the relatively few larger firms have strongly consolidated their international market share.

Overall, the regional expectations of increased production levels of shrimp have been high. However, both climatic (El Niño events in Ecuador) and pathogenic outbreaks (severe viral epizootics in Central and South America) have caused regional production to grow slower than expected over the last five years. The lower than expected growth rate has to a certain extent been counterbalanced by an expansion in the overall regional open pond surface area.

The regional aquaculture industry will face several challenges in the decade ahead. In particular these are: decreasing international prices for some species like shrimp and tilapia due to steady increases in supply; increasing cost of fishmeal; non-competitive energy and wage levels in some Latin American countries in relation to Asian producers and tougher environmental protection measures imposed by local governments as well as regional and international agreements, which result in higher investment costs to meet quality and sanitary standards.

Despite the challenges, the industry's horizon seems promising, stimulated by continued foreign investment, steady regional economic growth and stability and local economic diversification towards aquaculture. These factors, together with the increasing adoption of responsible, certifiable aquaculture practices by new and established farmers, ensure higher productivity, better quality and continued presence in both North American and European markets.

2. OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

2.1 Chile

The evolution of Chilean aquaculture can be divided into "before and after" the salmon industry. The first attempts to culture aquatic organisms in the country date back to 1850, with the introduction of rainbow trout and common carp. However, the sector only really took off in the early 1990s after the introduction of Atlantic salmon (*Salmo salar*).

Between 1993 and 2004 salmonid (trout and all salmon species) production increased seven-fold from 77 500 tonnes to 568 900 tonnes (FAO, 2006a). In 2002, salmon exports reached 350 000 tonnes (Figure 2), and in 2004 cultured salmon was second to copper in the ranking of Chilean export products, reaching US$1 439.4 million and representing five percent of the total national value of exports (Aqua.cl, 2005: www.aqua.cl). Other aquaculture species of economic importance in the country include rainbow trout (*Onchorhynchus mykiss)*, oysters (*Ostrea chilensis, Crassostrea gigas*), scallops (*Argopecten purpuratus*); macroalgae (*Gracilaria spp*); turbot (*Scophthalmus maximus*) and abalone (*Haliotis spp*) (Table 3).

Culture systems

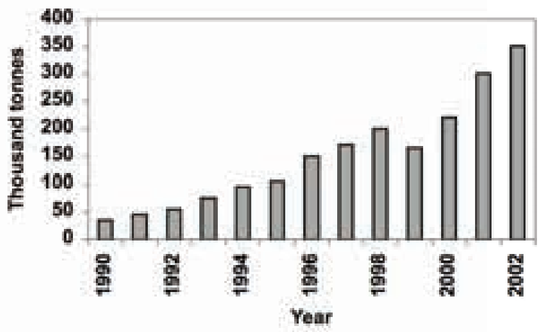
In general Chilean aquaculture is intensive and chiefly devoted to marine species, with the exception of rainbow trout. Coastal aquaculture is practically feasible in all regions of the country, although the density of aquafarms (salmon and trout), is significantly higher in southern areas (regions X and XI), due to the presence of fjords and other naturally protected areas (Figure 3). The culture of molluscs, flatfish and marine macrophytes is practiced mostly in the north, in regions III and IV. Table 4 summarizes the culture systems and production parameters of several commercially important aquaculture species of Chile.

TABLE 3
Production (tonnes) and value (thousand US$) of the most important aquaculture species in Chile for the period 1999–2003

Year	Atlantic salmon	Rainbow trout	Gracilaria	Oysters	Turbot	Abalone	Total export value
1999	179 774	50 414	31 278	26 400	333	48	-
2000	296 311	79 566	33 471	24 859	259	66	999 229
2001	460 065	109 895	65 638	25 852	303	73	1 002 026
2002	345 582	105 410	14 597	18 482	217	60	1 000 092
2003	377 350	109 658	16 259	18 723	340	80	1 177 954

Source: Aqua.cl magazine (March, 2005) available at www.aqua.cl

FIGURE 2
Evolution of Chilean salmon exports for the period 1990–2002



Source: Villarroel (2003)

FIGURE 3
Aerial view of a salmon cage farm in a Chilean Fjord

COURTESY OF M. ARANEDA

TABLE 4
Summary of culture parameters employed for important aquaculture species in Chile

Species	System	Culture facilities	Stocking density	Feeding	Source of larvae or juveniles
Atlantic salmon, *Salmo salar*	Intensive	Hatchery-reared alevines cultured in round tanks in freshwater until smolts are transferred to cages in estuaries and fjords	10 000/m^2 (alevines) 60–120 kg/m^3 (fattening)	45% protein	Artificial insemination in hatchery
Rainbow trout, *Onchorhynchus mykiss*	Intensive	2–6 m x 12–30m concrete or earthen raceways, water exchange: 100–400%/day in 90–230 m^3 cages	10–20 kg/m^3 (earthen ponds) 30–90 kg/m^3 (cages)	35–42% protein trout feed	Artificial insemination in hatchery
Red abalone, *Haliotis rufescens*	Intensive	Trocophore and veliger tank rearing. Settling tanks with algal grazing sheets. Juvenile rearing tanks (2x10m)	200–300/m^2 (larval stages) 60–100/m^2 (juveniles)	Diatoms *Macrocystis Gracilaria* and artificial feeds	Thermal or UV-induction to spawn

Source: M. Araneda, Universidad Católica del Norte, Chile (2006, pers. comm.)

2.2 Mexico

Although dating back to the late 18th century, aquaculture in Mexico only became an important economic activity in the early 1970s. Over the past three decades, the industry has grown rapidly in terms of production volumes, economic contribution and number of species cultured. In 2004, aquaculture production in Mexico amounted to 89 037 tonnes, which accounted for approximately 5.7 percent of the total national fisheries production (capture fisheries plus aquaculture) of 1.57 million tonnes (FAO, 2006a). The most important aquaculture species of the country, both by volume and value, are marine shrimp and tilapia. In 2002, shrimp and tilapia accounted for 73 and 14 percent in terms of total aquaculture produce value, respectively (SAGARPA, 2002), while in 2004 these proportions had shifted to 82.4 and 5.3 percent, respectively (FAO, 2006a). Pacific white shrimp (*Litopenaeus vannamei*) accounts for over 90 percent of shrimp production in Mexico.

Other finfish species include carp (*Cyprinus carpio*) along with Chinese carps, rainbow trout (*Oncorhynchus mykiss*), channel catfish (*Ictalurus punctatus*), largemouth bass (*Micropterus salmoides)* and the native white fish (*Chirostoma spp.).* The two most important mollusc species are *Crassostrea virginica*, which accounts for 97 percent of oyster production and the introduced *C. gigas*, through intensive, closed-cycle production, contributed with the balance (SAGARPA 2002), although the former is chiefly produced through enhanced fisheries. The industry is mainly concentrated in the north western states of the country.

TABLE 5
Percent contribution by species groups to total Mexican aquaculture production and value in 2004

Species groups	Percent contribution to total production	Percent contribution to total value
Shrimps	70.0	82.4
Tilapia	7.9	5.2
Carps	13.5	4.0
Trout	3.9	3.8
Tuna	0.6	2.5
Catfish	1.1	0.7
Shellfish	2.0	0.8
Others	1.0	0.6

Note: Total production = 89 037 tonnes; total value = US$291.33 million

Source: FAO (2006a)

Culture systems

Some 61 aquatic species are farmed in Mexico, for which a wide spectrum of aquaculture systems are employed, ranging from fisheries enhancement, culture in enclosures, extensive, semi-intensive and intensive pond culture as well as tanks and raceways. In the case of shrimp farming, larviculture is strongly encouraged by government, although small-scale farmers still depend on wild post larvae. Captive breeding is becoming a regular practice, although the majority of hatcheries still rely on wild breeders.

TABLE 6

Summary of aquaculture practices of commercially important aquaculture species in Mexico

Species	Farming/culture system	Culture facilities	Stocking density	Fertilization/ feeding	Source of larvae
Pacific white shrimp, *Litopenaeus vannamei*	Extensive	5–80 ha ponds with tidal or minimum water exchange (<5%/day stocked with wild PLs. No nursery stage[1] and generally with low input monitoring and management.	1–5 /m²	Inorganic fertilization sometimes supplemented with low quality shrimp feed.	Mostly seasonally caught larvae from the wild.
	Semi-intensive	2–25 ha ponds with pumped water exchange (5–30%/day), stocked mostly with hatchery-produced PLs. Nursery stage. Weekly monitoring for management decision making.	6–25 /m²	Initial inorganic fertilization. Supplementary shrimp feed throughout the culture period.	Hatchery-produced.
	Intensive	0.1–2 h ponds with pumped water exchange (30–100%/day). Acclimation period of PLs in pvc-lined[2] or fibreglass aerated raceways, nursery stage (2–3 weeks) in 0.01–0.1 earthen aerated ponds. High aeration practiced in on-growing ponds.	25–150 /m²	100% high quality shrimp feed. Use of probiotics is common.	Most intensive farms have hatcheries and produce their own postlarvae.
Tilapia, *Oreochromis spp.*	Cage culture	Two types: 56 m³ (7x4x2m) used in northern states, and 18 m³ (3x3x2m) used in southern states. Nylon, 0.75–1.5"-meshed bag with pvc frame and floats and mooring devices. Two stages: initial (10–50g) and terminal (50–450+g) on- growing stage.	Initial stage: 80–100/m³. Final stage: 50–75/m³	100% tilapia feed.	Hatchery-produced, sex-reversed fingerlings. Most farms buy from independent hatcheries.
	Semi-intensive pond culture	Breeding 0.1–-0.2 ha earthen ponds. In-pond incubation. Sex-reversal "happas" or tanks nursery ponds (0.1–0.5 ha) (from 0.1–10g). Transferred to initial on-growing ponds (0.1–0.75 ha) (from 10–40g). Transferred to final on-growing ponds (40–300g) Pumped water exchange (10–25 lps/ha[3]).	Broodstock: 1–2/m² Sex reversal: 2 000 /m³. Nursery: 120–150/m². Initial stage on-growing: 20–25/m². Final stage: 5–10/m²	Initial inorganic fertilization in nursery stage. Tilapia feed from nursery through to harvest.	Hatchery-produced, sex-reversed fingerlings. Most farms buy from independent hatcheries.
	Intensive pond/tank culture	Breeding in 0.1–0.2 ha earthen ponds. Egg collection and indoor incubation. Sex-reversal tanks (0.025 ha), nursery ponds (0.1–0.5 ha) (from 0.1–10g). Transferred to initial on-growing ponds (0.1–0.75 ha) (from 10–40 g). Transferred to intermediate ponds or raceways (0.1–0.15 ha) (40–150 g). Transferred to final stage ponds or raceways (0.1 ha), 100–400%/day water exchange.	Broodstock: 1–2/m² Sex reversal: 2 000–2 500/m³. Nursery: 120–300/m². Initial stage on-growing: 80–60/m². Intermediate stage: 40/m², final stage: 25/m².	High quality tilapia feed.	Hatchery-produced, sex-reversed fingerlings. All intensive farms produce their own seed.
Japanese oyster, *Crassostrea gigas*	Intensive raft/ long line	Mass production of spat in hatcheries: Broodstock thermally-induced to spawn. High (>150,000 cells/ml) algal counts are maintained in 5 m³-fiberglass round tanks. Larvae attach onto crushed or whole shells. Spat (3–4mm) transferred to shallow, productive coastal lagoons in either *Nestier* boxes or hanging ropes with shells in floating rafts.	Larval culture: 1–3 larvae/ml. *Nestier* boxes: Initial: 3 000 juveniles/box. Culled down to 80/box at harvest. Bags: 600/bag, culled down to 60/bag at harvest.	Larval culture: Axenic culture of phytoplankton. Grow-out: natural productivity.	Exclusively from hatchery

[1]No nursery stage implies that PL/fry are stocked directly into on-growing ponds, as opposed to stocking them in nursery ponds and then transferring for on-growing; [2]Polyvinyl chloride; [3]lps= litre per second

Source: author's database

A range of slight variants of the "Galveston method" are employed in the approximately 40 shrimp hatcheries in the country. However, standard techniques include mass-production of larvae in 10–20 m^3 indoor, highly aerated tanks, at densities ranging between 45 and 100/l. Apart from live food, supplementary feeding is a growing practice, including commercially produced dry, moist, semi-moist and liquid formulae.

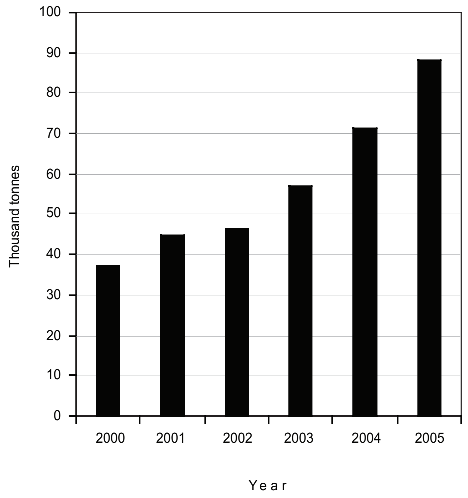
The bulk of tilapia farms (80 percent) have a closed-cycle operation, which allows for year round production of juveniles. Table 6 presents several culture systems and management practices used in Mexico.

2.3 Ecuador

Ecuadorian aquaculture began in the early 1970´s, when shrimp farming gradually replaced banana plantations along the coastal plains of Guayas Province. Ideal climatic conditions, low production costs and abundant naturally occurring shrimp larvae stimulated the impressive growth of the Ecuadorian shrimp farming industry over the last 30 years, thus becoming the largest marine shrimp producer of the Americas, and the number one exporter to the United States.

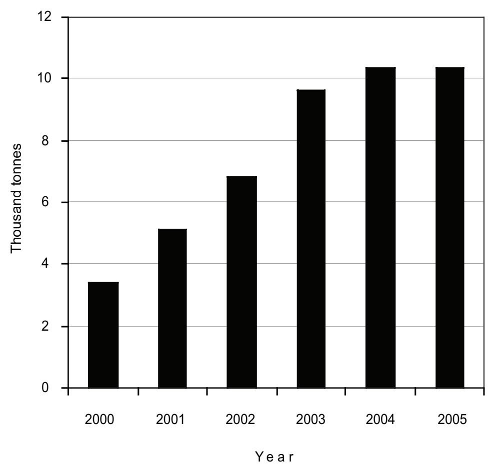
Despite favourable climatic conditions, the spectrum of aquaculture species of Ecuador is poor. Marine shrimp (Pacific white shrimp *L. vannamei* and blue shrimp *L stylirostris*), are by far the most important culture species, constituting 93.7 percent of the total national aquaculture production. The shrimp industry in Ecuador uses some 140 000 ha of extensive and semi-intensive ponds (National Agriculture Information Service, Ministry of Agriculture of Ecuador, 2004). However, viral epizootics badly impacted the shrimp industry during the 1980´s and 1990´s, resulting in significant reductions in shrimp production volumes. The industry began to recover in 2004/05 (Figure 4). As a result of the disease problems in the shrimp industry, farmers began to look for alternatives, among which tilapia has been the most popular choice. Figure 5 shows the trend in tilapia production, which has grown almost three-fold over the past 4 years.

FIGURE 4
National production of farmed shrimp in Ecuador for the period of 2000–2005 (production for 2005 is estimated)



Source: M. Dewind, National Chamber of Aquaculturists of Ecuador (2006, pers. comm.)

FIGURE 5
Aquaculture production of tilapia in Ecuador 2000–2005 (production for the year 2005 is estimated)



Source: M. Dewind, National Chamber of Aquaculturists of Ecuador (2006, pers. comm.)

TABLE 7
Summary of aquaculture practices for commercially important aquaculture species in Ecuador

Species	Farming system	Culture facilities	Stocking density	Fertilization/feeding
Shrimp, *Litopenaeus vannamei* *L. stylirostris* *L. occidentalis*	Extensive	5–30 ha ponds with tidal or minimum water exchange (<5%/day), stocked with wild or hatchery-reared PLs. Few with nursery stage and low input monitoring and management.	1–5/m^2	Inorganic or organic fertilization sometimes supplemented with low quality shrimp feed.
	Semi-intensive	1–10 ha ponds. 10–15%/day water exchange. Nursery and grow-out stages.	10–12/m^2	Inorganic fertilization and 20–35% protein shrimp feed. Use of probiotics.
Tilapia, *Oreochromis spp*	Semi-intensive	0.1–0.3 ha ponds. 10–100%/day water exchange. Nursery, juvenile and grow-out stages.	1–2.5/m^2	20–35% protein tilapia feeds.
Rainbow trout, *Oncorhynchus mykiss*	Intensive	2–6 m x 12–30m concrete or earthen raceways, water exchange: 100–400%/day	10–20 kg/m^3	35–42% protein trout feed

Source: M. Dewind, National Chamber of Aquaculturists of Ecuador (2006, pers. comm.)

Other species include the native fish Pacific fat sleeper *Dormitator latifrons*, rainbow trout *Oncorhynchus mykiss* and these are produced for the local market (M. Dewind, National Chamber of Aquaculturists of Ecuador, pers. comm.). The Australian crayfish/red claw *Cherax quadricarinatus*, introduced in 1988, became a popular species during the late 1980´s and early 1990´s, when over 50 farms were established. However, because of technical and market problems all have closed down. In addition, there are some 20 North American bullfrog (*Rana catesbeiana*) farms and all products are exported live.

Culture systems

Originally extensive shrimp farms have gradually been converted into semi-intensive and to a lesser extent intensive culture operations. This trend has been largely driven in an attempt to increase production and to prevent, through more rigorous control measures, further pathogenic catastrophes, such as the Taura and the white spot epizootics that severely hit the Ecuadorian shrimp industry during the 1990´s.

There is a growing tendency to introduce tilapia into shrimp farms, either in polyculture with shrimp or for parallel or rotational culture, thus reducing risks through diversification. The availability of idle processing facilities also provides an opportunity for expansion into fish processing. Table 7 summarizes the characteristics of the main culture systems employed in Ecuador.

2.4 Bolivarian Republic of Venezuela

As for the whole of Latin America, aquaculture in Venezuela is a relatively new economic activity. Its origins date back to the late 1930´s starting with the introduction of rainbow trout (*Oncorhynchus mykiss)* and common carp (*Cyprinus carpio).*

According to the National Fisheries Institute of Venezuela some 25 species are presently cultured in the country, at different levels of intensification. These include three exotic fish species (tilapia, rainbow trout and common carp) and 12 native species of finfish, including pirapitinga/black pacú, (*Piaractus brachypomus*), which with a production volume of 5 000 tonnes is the second most important aquaculture species in the country after shrimp; tambaqui (*Colossoma macropomum*), striped mullet (*Mugil cephalus*) and white bass (*Morone chrysops*), among others. Three species of marine shrimp, *Litopenaeus vannamei, L. stylirostris,* and *L. schmitti* are produced extensively and semi-intensively. In 2004, approximately 16 500 tonnes of shrimp were produced, which accounted for 74.3 percent of total production, while indigenous characins contributed about 22.5 percent (FAO, 2006a).

TABLE 8
Summary of aquaculture practices of commercially important aquaculture species in the Bolivarian Republic of Venezuela

Species	Culture facilities	Stocking density	Fertilization/feeding
Shrimp *L. vannamei* *L. stylirostris* *L. schmitti*	0.05–0.1 ha nursery raceways or ponds and 2–12 ha grow-out ponds	120–200/m^2 nursery 7–40/m^2 grow-out	Fertilizer and 25–35% protein feed
Tambaqui, *Colossoma macropomum*	0.05–0.1 ha ponds	1/m^2	Fresh fruits and 20% protein feed
Tilapia, *Oreochromis spp*	0.1–0.2 ha ponds	20/m^2 nursery and 3–5/m^2 grow-out	Pelleted feed
Rainbow trout, *Oncorhynchus mykiss*	12–30 x 2.5–8m raceways	10–24 kg/m^3	20–33% protein tilapia feed

Source: J. Velazco, National Fisheries and Aquaculture Institute, Bolivarian Republic of Venezuela (2006, pers. comm.)

Culture systems

Table 8 summarizes the main characteristics of the most representative culture systems employed by farmers in Venezuela.

2.5 Brazil

Aquaculture has been practiced in Brazil since the early 1900´s. Given its continental dimensions and climatic diversity, both temperate and tropical species are widely cultured. Currently, there are at least 64 species cultured in the country, including a number of native fish. Predominately based on small-scale farms, Brazilian aquaculture production in 2004 amounted to some 269 699 tonnes, valued at some US$965.6 million (FAO, 2006a). In 2003 there were approximately 100 000 farms occupying an area of 80 000 hectares. In 2004, finfish production comprised 62.7 percent by volume (66.3 percent by value) and shrimp production accounted for 28.1 percent by volume and 31.4 percent by value. Fish production was dominated by cichlids (25.6 percent), characins (mainly chachama) 17.9 percent and cyprinids (16.7 percent) (FAO, 2006a)

Shrimp farming began in the early 1980´s and after the introduction of *L. vannamei* in 1995 the industry expanded rapidly.

Culture systems

A wide range of aquaculture systems are employed in Brazil that include all levels of intensification, depending on the species, the region and the environment. Table 9 presents a summary of the main characteristics of the culture strategies for the most important aquaculture species of the country.

TABLE 9
Summary of culture systems for important aquaculture species in Brazil

Species Scientific name	Culture facilities	Stocking density	Fertilization/feeding
Shrimp, *L. vannamei* *L. stylirostris and L. schmitti*	0.05–0.1 ha nursery flow-through channels or ponds, and 2–40 ha grow-out ponds.	120–200/m^2 for nursery and 7–40/m^2 for grow-out	Fertilizer and 25–35% protein feed
Pacú, *Piaractus mesopotamicus*	0.05–0.1 ha ponds	1/m^2	Fresh fruits and 20% protein feed
Tilapia, *Oreochromis spp*	0.1–0.2 ha ponds 2–38 m^3 cages in reservoirs	20/m^2 nursery, 3–5/m^2 grow-out 80–100/m^3 juveniles and 20–50/m^3 final stage	Pelleted feed Extruded pelleted feed
Silver carp, *Hypophthalmichthys molitrix*; grass carp, *Ctenopharyngodon idella;* common carp, *Cyprinus carpio*	0.1–1.5 ha ponds	0.1–0.5/m^2 in polyculture	Organic and inorganic fertilizer; chopped grass.
Tambaquí, *Colossoma macropomum*	0.05–0.1 ha ponds 2–16 m^3 cages	0.25–1.0/m^2 30/m^3 initial stocking and 10–15/m^3 final stage	Chopped meat and fruits in juveniles and 20% pelleted feed in final stage
Rainbow trout, *Oncorhynchus mykiss*	12–30 x 2.5–8m raceways	10–24 kg/m^3	20–33% protein tilapia feed

Source: FAO Fisheries Global Information System (2006); M. Hipólito, Biology Institute of Sao Paulo, Brazil (2005, pers. comm.)

2.6 Cuba

Aquaculture is a strategic activity in Cuba both for producing animal protein and for earning foreign currency through export. The absence of suitable native species for cost-effective aquaculture was the reason for introducing a wide range of species. These are cultured both extensively and semi-intensively in more than 148 000 ha of small to medium sized reservoirs nationwide. In addition, there are 26 state-owned and operated fish breeding stations where fry of different species are mass produced and distributed to 30 stations for on-growing with approximately 1 000 ha of fish ponds. In 2004, total Cuban aquaculture production amounted to some 27 562 tonnes valued at US$29.4 million (FAO, 2006a).

Fish is the most important product and collectively contributed 94.3 percent to total production by volume and 91.3 percent by value (FAO, 2006a). The main species are Oreochromis spp, common carp Cyprinus carpio, channel catfish *Ictalurus punctatus*, and Chinese grass carp *Ctenopharyngodon idella* and silver carp *Hypophthalmichthys molitrix*. The white shrimp L. vannamei and the native white shrimp L. schmitti are cultured in 4 semi-intensive farms, using larvae produced in 3 hatcheries. Total production of farmed shrimp was 1 370 tonnes in 2003, which then accounted for 5.1 percent by volume and 17.2 percent by value (the reported production for 2004 was 390 tonnes, but it is not known whether this is an error) (FAO, 2006a). Other species cultured in the country are the African catfish Clarias gariepinus and the Australian crayfish Cherax quadricarinatus, which were recently introduced.

Culture systems are mostly extensive. Stock enhancement is largely practiced through stocking of hatchery-reared fingerlings in large to medium sized reservoirs, which sometimes are organically or inorganically fertilized, as well as in earthen ponds that range from 0.01–0.3 ha. Most finfish species are stocked at between 0.1 and $2/m^2$ and fed a wide variety of locally available protein sources, since aquaculture feeds are almost only available for shrimp farming.

Shrimp farming is semi-intensive. Hatchery-reared post-larvae are stocked in previously fertilized ponds at densities that vary between 80 and $150/m^2$ during the nursery stage and between 12 and $20/m^2$ in the growout stage. Shrimp are fed 20–35 percent protein feeds. Water exchange in shrimp ponds fluctuates between 3 and 15 percent/day and aeration is not employed (Toledo, 2004).

3. REVIEW OF FERTILIZERS AND FERTILIZATION

Fertilization of aquaculture ponds for tropical species is a wide-spread practice throughout Latin America. The exceptions are Chile, where temperate species such as Atlantic salmon and abalone are reared intensively and other intensive farms in the region where the species depend entirely on commercial feeds.

Given that shrimp and tilapia farming are the most important aquaculture activities in Latin America, except Chile, management strategies including fertilization are similar in most countries. Furthermore, international trade in fertilizers is dynamic within the region, such that a variety of brands with different chemical compositions are readily available.

3.1 Inorganic fertilization

Brackish-water aquaculture

The majority (more than 80 percent) of shrimp farms in the region are considered to be semi-intensive. Although higher levels of control and inputs are increasingly being introduced to counteract possible pathogenic outbreaks, shrimp are still partially dependent on natural pond productivity that is enhanced through the application of inorganic fertilizers. Application rates and strategies have been standardized through research by fertilizer companies and the academic sector.

A rapid survey carried out as part of the present analysis in Mexico, Guatemala and Belize showed that respectively 22 out of 27 (81 percent); 8 out of 8 (100 percent) and 4 out of 5 (80 percent) of the surveyed farmers use indirect or subjective methods (Secchi disk or apparent colour of pond water) to determine whether a pond should be fertilized or not, and only 4 out of 40 (10 percent) employ direct phytoplankton counts as an indicator of the need to fertilize.

Two common application methods employed by shrimp farmers in the region were observed during the present analysis, viz. direct application of water-dissolved fertilizers and a point-source gradual release method. Direct application involves calculating the amount of different fertilizers required according to standard equations, dissolving the mixed fertilizers in water and applying the solution to ponds in which the water level has been reduced to around 0.1 m during peak light hours, where after the pond is gradually filled. The point-source application method is more commonly used by small-scale farmers. It also involves calculating the required quantity of fertilizer per pond and then dividing it into several bags through which nutrient leaching can take place. The bags are submersed and tied to poles in the pond that have been arranged in a pattern to ensure homogenous distribution of nutrients.

Inorganic nitrogen and phosphorus fertilizers are available in all countries of the region. Table 10 presents a summary of chemical composition and application rates of inorganic fertilizers employed by shrimp farmers in a selected number of countries in Latin America.

A typical inorganic fertilization strategy employed by Brazilian farmers is presented in Table 11. In some regions where soils are low in silicon, Sodium metasilicate is applied at a rate of 750 cm^3/ha (Nunes, 2000).

TABLE 10
Summary of inorganic fertilizer application methods employed by shrimp farmers in Latin American countries

Fertilizer	Composition (% N, P and K)	Chemical composition	Application rate/cycle	Degree of use	Country
Urea	46-0-0	NH_2-CO-NH_2	20–24 kg/ha	***	Brazil, Colombia, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Panama, Peru, Bolivarian Republic of Venezuela
Single superphosphate	0-20-0	$Ca(H_2PO_4)_2$	1.3–3.9 kg/ha	**	Brazil, Ecuador, Mexico
Triple superphosphate (TSP)	0-42-0	$Ca(H_2PO_4)_2$	0.9–2.4 kg/ha	***	Brazil, Colombia Cuba, Ecuador, El Salvador, Honduras, Mexico, Panama, Peru, Bolivarian Republic of Venezuela
Diammonium phosphate (DAP)	16-24-0	$(NH_4)_2HPO_4$	0.9–3.0 kg/ha	*	Ecuador, Mexico, Honduras, Panama
Monoammonium phosphate	8-24-0	NH_4HPO_4	3.7–5.2 kg/ha	**	Ecuador

***Widely used, **Common, *Low use

Sources: MIDA (1998); Nunes (2000, 2004); J. Zendejas, Cargill-Purina, Mexico (2006, pers. comm.); author's own data

TABLE 11
Standard inorganic fertilization procedure employed by Brazilian shrimp farmers

	Procedure (steps)	Application rate
1	Pond water level is raised to 0.3 m	9 kg urea + 0.9 kg TSP/ha
2	Pond left for two days to bloom	
3	Pond water level raised at 50% the operational level	14 kg urea + 1.4 kg TSP/ha
4	Pond water static for 3 days to bloom	
5	Pond water level raised to full level (0.9–1.1 m)	23 kg urea + 2.3 kg TSP/ha
6	Pond water static for another five days	
7	Stocking of juveniles. Water exchange starts and is gradually increased.	Maintenance rates according to pond productivity

Source: Cook and Clifford (1998)

TABLE 12
Combined (organic/inorganic) fertilization strategy employed by Ecuadorian shrimp farmers

Fertilizer	Initial application rate (kg/ha)	Maintenance application rate (kg/ha)*
Dried chicken manure	1 000	0
Ground rice bran	50–200	6.8
Urea	28	2.4
Monoammonium phosphate	2.4	0.4
Sodium metasilicate	10	1.5

*If Secchi disk reading >45 cm
Source: Nicovita (1999)

In a relatively small proportion of farms (approximately 13 percent in the case of Mexico and 25 percent in the case of Ecuador) a combination of inorganic and organic fertilizers is employed. A typical combined fertilization strategy employed by Ecuadorian shrimp farmers is presented in Table 12.

In Cuba, inorganic fertilizer is applied routinely during the production cycle of *Cherax quadricarinatus*. Dry chicken manure (500 kg/ha) and hay (1 000–1 250 kg/ha) are applied prior to stocking juveniles in grow-out ponds (Toledo, Centro de Preparación Acuicola Mampostón, 2005, pers. comm).

A new generation of more specifically "aqua-balanced" fertilizers is being used in some countries of the region. Such is the case of a product called *Fertilizarina* (Protinal-Proagro, Venezuela) manufactured in Venezuela and sold locally. This product is an organic aquaculture fertilizer with a C:N ratio of 25:1 that has been specifically designed to enhance microbiotic colonization of the pond, thus stimulating the development of the heterotrophic food web.

Freshwater aquaculture

Because of the increasing shift towards intensification, inorganic fertilization of freshwater aquaculture ponds is declining in the Americas. Only a few species of commercial relevance are cultured in extensive and semi-intensive farming systems using chemical fertilizers, e.g. monoculture of tilapia and common carp and to a lesser extent polyculture of Chinese carps in certain areas in Brazil and Mexico. A typical fertilizer schedule for juvenile tilapia in Ecuador is Urea at 20–30 kg/ha and TSP at 2–5 kg/ha. In southern Mexico, tilapia farmers administer single superphosphate at 8 kg/ha (dissolved in water) prior to stocking fingerling ponds. Depending on water turbidity, they subsequently apply 200–250 kg/ha of dried chicken manure.

3.2 Organic fertilization

Some of the larger semi-intensive shrimp and/or tilapia farms, medium-sized fish (carp or tilapia) and red claw farmers and many small-scale farmers use manure as fertilizer. However, given the availability and relatively low price of chemical fertilizers, the overall use of animal manure and or other forms of organic fertilizers in aquaculture is limited.

Animal manure is the most widely used form, although many other agriculture by-products are used to enhance nutrient levels in ponds. Table 13 presents a summary of such products with recommended application rates.

TABLE 13
Organic nutrients used as aquaculture fertilizers in Latin American countries

Source of nutrient	Standard application rate*	Species cultured	Countries	Level of aquaculture
Chicken manure	250–500 kg/ha	Shrimp, tilapia, carp, red claw	Mexico, Ecuador, Cuba, Panama, Honduras, Brazil, Guatemala, Peru, Bolivarian Republic of Venezuela	Commercial
Cattle manure	500 kg/ha	Carps	Brazil, Cuba	Commercial
Pig manure	550–750 kg/ha	Carps, tilapia	Cuba	Commercial
Rice bran	300–400 kg/ha	Shrimp	Brazil, Ecuador, Mexico	Commercial
Sugar cane fibre	800 kg/ha	Shrimp	Belize, Brazil, Cuba, Honduras	Commercial
Molasses	19–120 kg/ha/week	Shrimp	Belize, Ecuador, Panama, Peru,	Commercial
Molasses	30–120 kg/ha	Shrimp	Colombia	Commercial
Chopped fresh vegetable	1 000–1 250 kg/ha	Tilapia, pacú	Brazil, Cuba, Mexico, Bolivarian Republic of Venezuela	Subsistence
Chopped weed	2 000–2 500 kg/ha	Tilapia	Guatemala, El Salvador, Mexico, Panama	Subsistence
Soybean meal	300–500 kg/ha	Shrimp	Brazil, Ecuador, Mexico, Honduras, Panama	Commercial
Alfalfa meal	280 kg/ha	Tilapia	Mexico, Panama	Experimental
Hay	1000–1 250 kg/ha	Red claw	Cuba	
Chaya (green leaves)	20–30 kg/100 m^2/day	Tilapia	Mexico	Subsistence
Coffee pulp	300–600 kg/ha	Tilapia, carp	Cuba, Brazil, Mexico	Subsistence

Sources: Palomo and Arriaga (1993); MIDA (1998); Olvera (1994); S. Toledo, Mampostón, Cuba (2005, pers. comm.); M. Guillian, Ecuador (2006, pers. comm.); J. Zendejas, Cargill-Purina, Mexico (2005, pers. comm.)

3.3 Availability

Chemical fertilizers are inexpensive and readily available throughout Latin America, due to an ever increasing demand by large and small-scale agriculture. The demand for fertilizers by agriculture is several orders of magnitude higher than the demand from aquaculture, hence aquafarmers are largely reliant on the types and composition of chemical fertilizers used by their local agriculture counterparts. Any shifts in the agriculture demand for certain fertilizers may hold distinct disadvantages for aquafarmers. For example, because of decreasing demand the largest producer of fertilizer in Mexico stopped the production of urea in 1998 (Espinosa-Carmona, 2002) (Table 14), one of the most common nitrogen sources for aquaculture ponds in Mexico. Since then urea is imported and this has put pressure on the price.

Throughout the region there is very little structured research on fertilization in aquaculture, hence the adoption of general standard rates and methods of application. For example, farmers take little cognisance of soil or incoming water chemistry.

Organic fertilizers are widely available throughout Latin America. The agriculture-based economy of many of the countries in the region, provide a huge potential resource base. The overall tendency to intensify culture practices on large-scale farms, together with a more efficient cost/benefit ratio of using readily available inorganic fertilizers, has encouraged the use of chemical as opposed to organic inputs. The rapidly emerging demand for organically-grown products may however stimulate the demand for organic nutrient sources by aquaculture.

TABLE 14
Production of inorganic fertilizers in Mexico between 1980 and 2000 (thousand tonnes)

	Year				
Fertilizer	1980	1985	1990	1995	2000
Urea	401	1367	1415	1508	0
Ammonium sulphate	1069	1614	1596	1108	1446
Diammonium phosphate	111	91	684	540	290
Single superphosphate	275	314	176	117	75
Triple superphosphate	115	253	235	281	85

Source: Espinosa-Carmona (2002)

Generally speaking, prices of inorganic fertilizers are relatively low. The cost of inorganic fertilization usually accounts for 5 percent of the costs of feeds in shrimp farms (Flores-Nava, 1994). Prices of organic fertilizers have been gradually increasing as a result of a growing demand for manure as a source of protein in animal husbandry (e.g. reaching US$130/tonne for chicken manure in Mexico).

3.4 Sustainability

Table 15 presents a summary of factors affecting the sustainable use of fertilizers in Latin American aquaculture.

TABLE 15
Summary of positive and negative externalities likely to affect the sustainability of the use of fertilizers in aquaculture in Latin America

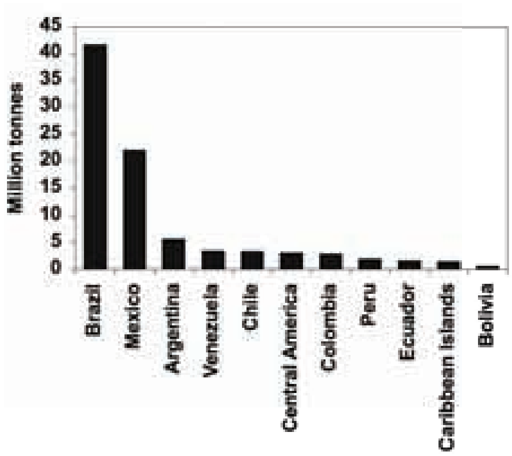
Factor	Inorganic fertilizers		Organic fertilizers	
	Positive	Negative	Positive	Negative
Form of production	Increased number of industries (i.e., Brazil and Mexico) that produce nitrogen fertilizers in sustainable forms (atmospheric sources)	Risk of decline of phosphoric rocks if used in excess	Sustainable if sources are chemical-free	Intensive form of agriculture or animal husbandry involves the use of antibiotics or pesticides that can be transferred in by-products used in aquaculture
Potential environmental impact of use	Possibility of using the adequate chemical balance for the type of water and/or soil where it is to be applied	Increasing risk of eutrophication of receiving water bodies. Most countries in the region still with soft control measures	Could be a stimulating factor for re-using agricultural wastes, thus reducing organic discharges.	Potential dissemination of pathogens if manures are not certified by sanitary personnel.
Market related issues	Inexpensive due to large supply for the agriculture sector	Specific availability dependent on the needs of the local agriculture sector. Ecological awareness of consumers will decrease demand for chemical inputs	Wide spectrum of inexpensive nutrient sources locally available in every region. Growing demand for "organic" labelled products will trigger demand for organic inputs.	Opportunity cost of avian manures is high due to growing demand as a source of protein for cattle or pigs. An increase in the demand by the "organic aquaculture" sector is likely to put further pressure on prices.
Legal aspects	Growing concern puts pressure on governments for tougher regulations	Adequate regulations still a long way from becoming strict laws.	Pressure upon agriculture and live-stock farmers to adequately dispose wastes. Their use in aquaculture could be a solution	No regulations regarding possible toxicity or pathogenicity of animal or agricultural by-products
Availability	Widely available	Limited diversity	Widely available. Possibility of widening the spectrum of nutrient sources	Increasing demand for a wider spectrum of users will affect availability in the short term

4. THE AQUAFEED INDUSTRY IN LATIN AMERICA

The animal feed milling industry of Latin America has grown steadily over the past 30 years, as a result of the intensification and expansion of the poultry, cattle, pig and aquaculture sectors throughout the region. Brazil and Mexico rate among the worlds top 10 animal feed producing nations (J. Cordeiro, Assoc. Nacional de Fabricantes de Alimentos do Brasil (ANFAL), Brazil, 2005, pers. comm.). Animal feed production in Latin American countries is summarized in Figure 6 and Table 16 summarizes aquafeed production in the six target countries as well as in Guatemala.

Salmon, shrimp and tilapia farming are the largest and most dynamic aquaculture activities in the region and the overall volume of aquafeed production is largely a reflection of the performance of these sectors in each country. Large-scale events such as over-production of feeds or the outbreak of epizootics can have a direct and serious impact on the aquaculture sector, inclusive of the aquafeed industry.

FIGURE 6
Production of animal feeds in Latin American countries in 2003



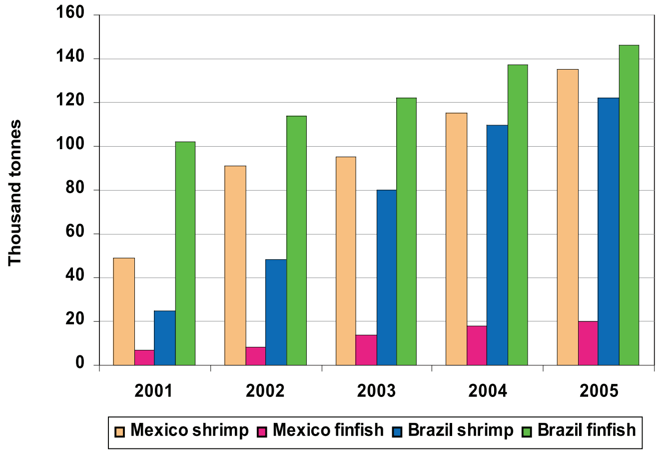
Source: J. Cordeiro, ANFAL, Brazil (2005, pers. comm.)

Figure 7 shows the production of shrimp and tilapia feeds in Brazil and Mexico. After an unprecedented increase in shrimp feed production of 46 percent in 2002, severe viral epizootics hit the Mexican shrimp farming sector, thus drastically reducing to only 4 percent the expected feed demand, despite an expansion of more than 10 percent in the shrimp culture surface area. Ecuador, the largest shrimp producer on the continent has also been severely hit by a range of viral epizootics. The first occurred in the early 1990´s when Taura syndrome caused a reduction of over 20 percent in the overall shrimp production and then in 1999, a year on year collapse of nearly 50 percent caused by "white spot" disease. Similar events have been experienced throughout Central America and all have had a negative impact on aquafeed production in the region.

TABLE 16
Production of aquaculture feeds, percent contribution to total national animal feed production and the number of aquafeed mills in several Latin American countries in 2003

Country	Number of feed mills producing aquafeeds	Production of aquafeeds in 2003 (tonnes)	% of national total animal feed production	Source
Chile	10	750 000	15	Villarroel (2003), Infante (2003)
Brazil	30	200 000	0.5	Waldige and Caseiro (2003); Scorvo (2003)
Mexico	11	109 000	0.7	Panorama Acuicola (2004a)
Ecuador	12	97 000	6.9	M. Dewind, National Chamber of Aquaculturists of Ecuador, pers. comm. Sistema de Información Agropecuaria de Ecuador (2003, pers. comm.)
Bolivarian Republic of Venezuela	4	30 000	1.7	J. Velazco, National Institute of Fisheries, pers. comm.
Cuba	2 (one experimental)	4 000 (commercial shrimp feed) and 187 000 silage (experimental)	–	S. Toledo, Centro de Preparación Acuícola Mampostón, Cuba, pers. comm. and Toledo (2004)
Guatemala	1	8 000	2	J. Zendejas, Cargill-Purina, pers. comm.

FIGURE 7
Shrimp and finfish feed production in Brazil and Mexico during the period 2001–2005 (figures for the year 2005 are estimated)



Source: Waldige and Caseiro (2003); J. Zendejas, Cargill-Purina, Mexico (2005, pers. comm.)

5. A REVIEW OF FEEDS AND FEEDING IN AQUACULTURE

5.1 Feed composition

Although only a few large feed companies compete for the growing aquafeed market in the region, there is a wide spectrum of brands, species-specific feeds and formulations available in the Americas. Typical proximate analyses and compositions of commercial shrimp and freshwater fish feeds in Latin America are presented in Tables 17 and 18.

In Brazil and Mexico manufacturers recognise the growing environmental concerns and state that their feeds are highly water stable to minimize leaching of nutrients such as phosphorus into the environment. Paradoxically, feeds in Brazil have the highest phosphorus levels in the region.

Water stability of shrimp feeds varies between 30 minutes and 3 hours, depending on the binding agent used (author's observations).

Water stability of pellets depends on the processing technique. Sinking pellets for catfish and carp have a low stability (3–15 minutes, according to Nicovita, Ecuador), while extruded floating pellets are significantly more water stable.

TABLE 17

Proximate composition of commercial marine shrimp diets in selected Latin American countries

Country	Crude protein	Crude lipid	Crude fibre	Phosphorus	Sources (Brand)
Brazil	25–40	5.0–8.0	4.5–6.0	0.7–1.45	www.agribrands.com.br www.guabi.com.br www.classipet.com.br
Ecuador	20–45	5.0–8.0	3.0–5.0	1.0–1.5	www.nicovita.com.ec
Guatemala	20–35	6.5–8.5	4.0–5.0	0.9–1.25	www.agribrands.com.gu
Mexico	20–40	6.0–9.5	4.0–5.0	0.9–1.25	www.agribrands.com.mx www.nutrinas.com.mx www.piasa.com.mx www.ziegler.com.mx
Panama	20–35	4.0–9.0	3.5–6.0	1.20	J. Zendejas (2005, pers. comm.); Agribrands Purina, Mexico (2005, pers. comm.)
Bolivarian Republic of Venezuela	25–35	4.0–8.0	3.0–5.0	0.9–1.4	www.agribrands.com.ve

TABLE 18

Proximate composition of commercially available finfish feeds in Latin America

	%	Tilapia	Carp	Trout	Sources (Brand)
BRAZIL	Crude protein	20–42	20–35	30–55	www.agribrands.com.br www.classipet.com.br www.cocari.com.br www.guabi.com.br www.socil.com.br
	Crude lipid	4–6	3–6	6–12	
	Crude fibre	6–10	6–10	4–5	
	Phosphorus	0.6–1.2	0.6–1.2	0.6–1.0	
ECUADOR	Crude protein	25–45	-	35–50	www.nicovita.com.ec M. Dewind, National Chamber of Aquaculturists of Ecuador, (2005, pers. comm.)
	Crude lipid	3–6	-	6–9	
	Crude fibre	5–9	-	4–6	
	Phosphorus	0.9–1.3	-	0.9–1.0	
MEXICO	Crude protein	25–42	22–30	35–55	www.agribrands.com.mx www.nutrinas.com.mx www.ziegler.com.mx
	Crude lipid	3–4	3–4	8–12	
	Crude fibre	5–10	5–10	4–6	
	Phosphorus	0.7–1.0	0.7–1.0	0.9–1.2	
BOLIVARIAN REPUBLIC OF VENEZUELA	Crude protein	20–28	-	40–45	www.agribrands.com.ve
	Crude lipid	5.0–6.5	-	10–12	
	Crude fibre	3–6	-	3–6	
	Phosphorus	1.0–1.2	-	0.9–1.2	

5.2 Ingredients

Fishmeal continues to be the core protein source employed by aquafeed manufacturers in Latin America. Other major protein sources include commodities such as soybean meal and wheat meal, prices of which are a function of global availability and exchange rates. These key standard ingredients are common to practically all commercially available aquafeeds throughout the region and are traded within the region.

Other ingredients commonly used in aquafeed formulations include maize, sorghum, wheat bran, maize gluten, cottonseed meal, groundnut meal, sesame meal, meat meal, feather meal and alfalfa meal. For example, a Venezuelan aquafeed manufacturer (Protinal, Zulia, Venezuela) reports the following ingredients in some of their formulations: fish, soybean and meat meals; wheat bran, stabilized fat, fish oil, calcium carbonate and calcium phosphate, trace minerals (Co, Zn, Mn, Cu, Se, I); vitamins A, B1, B2, B6, B12, C, D, E, K, folic acid, biotin, pantothenic acid, choline, niacin and inositol.

Table 19 summarizes the most common protein sources employed by aquaculture feed manufacturers in Latin America, their country of origin, as well as some market related factors likely to affect their availability and prices.

Generally speaking, the core protein sources employed by the Latin American aquafeed industry are global commodities for which there is a high international demand. World prices for fishmeal, corn, wheat and soybeans show an increasing trend because of increasing demand and declining supplies caused by climatic events.

TABLE 19
Most important protein sources used by aquafeed manufacturers in Latin America and factors likely to affect their sustainable use

Source of protein	Degree of availability	Countries that produce it in the region	Market/price-related constraints to the aquaculture industry
Fishmeal	High	Chile, Peru, Ecuador, Brazil and Mexico. (only relatively small volumes produced in Brazil and Mexico)	Prices have steadily increased as a direct function of global demand. Climatic changes have had an impact on catches
Soybean meal	High	Brazil, Argentina, Uruguay, Mexico	Regardless of local availability, prices are determined by global supply/demand. Price of this commodity has increased from US$92/tonne in 2000, to US$221/tonne in 2003.
Corn	High	Argentina, Brazil, Mexico, Colombia	High demand for direct human consumption (Staple diet in many countries of the region) puts pressure on prices, which combined with local crop failures have increased prices by 100% in Brazil, or between 25 and 35% in Mexico
Blood meal, bone and meat meals	Medium	Argentina, Uruguay, Paraguay, Colombia, Mexico, Bolivarian Republic of Venezuela	By-products of the cattle farming industry. Mostly consumed locally, due to sanitary regulations. Production in some countries like Mexico and Paraguay, impacted indirectly by imports of low-cost meat, which results in local herd reduction.
Wheat bran	High	Argentina, Brazil, Colombia, Mexico	Argentina is one of the top world producers and has experienced a reduction in production due to adverse climatic conditions. Prices are also a function of world supply and demand, and increased 100% between 2000 and 2002.
Lupin seed	High	Chile, Argentina	Most of the production devoted to salmonid aquaculture. Culture areas expected to expand to meet aquaculture needs.

Source: Waldige and Casseiro (2003); Panorama Acuícola (2004a); Ministerio de Agricultura de Ecuador (2004); J. Cordeiro, ANFAL, Brazil (2005, pers. comm.); J. Zendejas, Cargill-Purina, Mexico (2005, pers. comm.); Infante (2003)

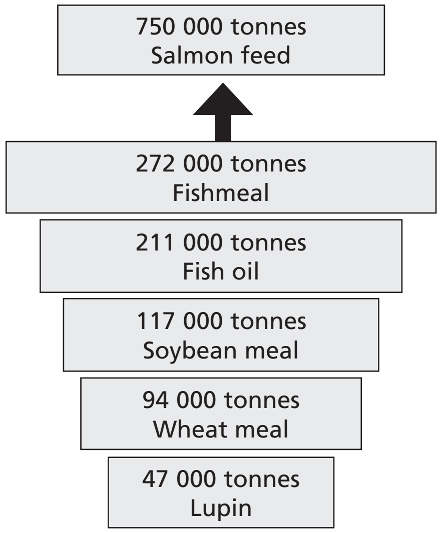
5.3 The case of Chilean salmon feeds

If aquaculture is to be sustainable in Latin America then a good example of the challenges facing the industry is the case of the salmon feed industry in Chile. In 2003, the salmon industry demanded 750 000 tonnes of feed, which included some 272 000 tonnes of fishmeal (this accounted for 78 percent of Chilean fishmeal usage in that year).

The industry also consumed 211 000 tonnes of fish oil, and a high proportion of grains produced both in and out of the country (Figure 8).

Chilean production of salmon is expected to grow at an average rate of 10 percent per annum for the foreseeable future (Infante, 2003). At this pace, within the next ten years, an additional 110 000 ha of wheat and lupin as well as 780 000 tonnes of fishmeal will be needed exclusively to meet the core demands for salmon feeds.

FIGURE 8
Schematic representation of the ingredient demand by the Chilean salmon industry in 2003



Source: Modified from Infante (2003)

5.4 Alternative protein sources

Following a global tendency, several research groups particularly in Chile, Ecuador, Mexico and Brazil have been working to identify and test a range of protein sources to replace fishmeal.

However, despite the high biodiversity in countries like Brazil, Ecuador and Mexico, research and financial resources devoted to aquaculture nutrition and more specifically to finding fishmeal replacements in the region are still very modest. Hence the Latin American aquafeeds industry is still almost exclusively dependent on the core protein sources mentioned above. Table 20 lists a number of alternative protein sources that have been tested experimentally or commercially in some countries in the region.

Lipid sources include mostly fish oil, sunflower oil, corn oil, soybean oil and cottonseed oil. The main regional producer and exporter of fish oil, which is by far the most common lipid source used in aquafeeds, is Chile followed by Peru. Lower quality fish oil is produced in smaller quantities in Mexico, Brazil and Ecuador, although mostly for domestic consumption. Vegetable oils are mainly produced in Mexico,

TABLE 20
Summary of non-conventional protein sources that have been tested and or used in some Latin American countries

Common name	Scientific name	Species cultured	Purpose	Source
Coffee pulp	*Coffea arabica*	Tilapia	Experimental	Bayne, Dunseth and Ramiros (1976)
Rum distillation wastes		Tilapia	Experimental	Kohler and Pagan-Font (1978)
Yeast	*Hanola anomala*	Rainbow trout	Experimental	De la Higuera *et al.* (1981)
Azolla	*Azolla mexicana*	Tilapia, carp	Experimental	Arrivillaga and Arredondo (1987)
Lupin seed	*Lupinus spp*	Rainbow trout	Experimental	De la Higuera *et al.* (1988)
Jack bean seed	*Canavalia ensiformis*	Tilapia	Experimental	Martínez *et al.* (1988)
Huaxim seed	*Sesbania grandiflora*	Tilapia	Experimental	Olvera *et al.* (1988)
Alfalfa leaves	*Medicago sativa*	Tilapia	Experimental	Hernández, Hernández and Martinez (1991)
Dendrocéfalo	*Dendrocephalus geayi*	Tambaquí	Experimental	Torres *et al.* (2003)
Daphnia/fly larvae	*Daphnia spp* *Culex quinquefasciatus*	*Cichlasoma istlanum*	Experimental	Luna and Figueroa (2003)
Langostilla	*Pleuroncodes planipes*	Shrimp	Experimental	Galicia (2003)
Fish silage	-	Tilapia, carp, Catfish (*Clarias* spp.)	Experimental and commercial	Toledo (2004)
Kelp	*Macrocystis pirifera*		Commercial	Panorama Acuícola (2004b)

Brazil, Argentina, Chile and Colombia and to a lesser extent in Uruguay and Venezuela. Nonetheless, feed manufacturers import large quantities of high quality vegetable oils from the United States of America and Canada. Prices of fish and vegetable oils have increased substantially with increasing demand and reduced availability because of periodic crop failures.

5.5 Feeding strategies

Shrimp farming

Feeding regimes and strategies are similar throughout Latin American aquaculture. In general, farmers follow the recommendations and advice provided by technical staff of large feed manufacturing companies.

The great majority of shrimp farms (more than 90 percent) produce Pacific white shrimp, *Litopenaeus vannamei*, therefore practically 100 percent of the commercially available feeds are designed to meet the nutritional requirements of this species. The most common practice is to follow feeding tables recommended by feed manufacturers. These normally take into account standard stocking densities and climatic conditions of the region. Table 21 presents standard feeding regimes followed by farmers in Brazil, Ecuador, Mexico, Panama and Peru.

TABLE 21
Feeding regime employed by Pacific white shrimp (*Litopenaeus vannamei*) farmers in Latin America

Shrimp weight (g)	% body weight/day				
	Brazil[1]	Ecuador[2]	Mexico[3]	Panama[4]	Peru[5]
1	13	-	16	12	14
2	11	5.5	11.7	10	8.2
3	10.5	4.7	8.6	9.0	6.2
4	10	4.2	7.2	9.0	5.2
5	9.3	3.9	6.2	8.0	4.5
6	9.0	3.6	4.8	8.0	3.9
7	8.4	3.3	4.4	7.0	3.6
8	8.0	3.0	4.0	7.0	3.3
9	7.2	2.9	3.9	6.5	3.0
10	6.3	2.8	3.6	6.0	2.8
11	5.7	2.6	3.5	5.5	2.6
12	5.0	2.6	3.3	5.3	2.5
13	4.2	2.5	3.1	5.1	2.3
14	3.4	2.4	3.0	4.8	2.2
15	3.0	2.3	2.9	4.8	2.1
16	2.5	2.3	2.7	4.5	2.0
17	2.4	2.2	2.5	4.0	2.0
18	2.4	2.1	2.4	3.5	1.9
19	2.4	2.0	2.4	3.0	1.8
20	2.4	2.0	2.4	2.5	1.8
21	2.4	1.9	2.4	2.5	1.8
22	2.4	1.8	2.4	2.5	1.8

Sources: [2]Villalón (1991); [1,5]Nunes (2000); [4]CODECA (2004); [3]Zendejas (2005)

5.6 Feeding schedules and practices

Farmers normally feed their fish or shrimp between noon and sunset to avoid low DO periods. Throughout Latin America shrimp farmers feed a minimum of 2 and a maximum of 4 times a day, depending on the number and size of ponds and the available workforce. A recommended feeding schedule for white shrimp, *Litopenaeus setiferus* in Yucatan, southeast Mexico is presented in Table 22.

Over the past 10 years, Latin American shrimp farmers have increasingly adopted the use of feeding trays, as opposed to feeding manually with the aid of a boat. Feeding trays are circular in shape, between 0.60 and 1.20m in diameter and usually made of galvanized wire and plastic mosquito mesh. Such trays are evenly distributed throughout the pond, at between 20 and 30 trays/ha. Farmers place the corresponding sub-ration of feed into each tray at pre-specified periods. The use of feeding trays is becoming very popular due to their usefulness in monitoring the feeding activity of shrimp as well as reducing the accumulation of wastes on the pond bottom.

TABLE 22
Recommended feeding schedule for white shrimp, *Litopenaeus setiferus* in semi-intensive ponds in Yucatan, southeast Mexico

Shrimp size (g)	Feeding schedule	% of daily ration
1.0–3.0	11:00	50
	17:00	50
3.1–6.5	11:00	40
	17:00	30
	22:00	30
>6.5	11:00	40
	14:00	10
	17:00	10
	21:00	40

Source: Flores-Nava (1994)

Finfish

Given the level of intensification of salmon and trout culture, automatic feeding is employed in most farms, on a continuous intermittent basis. Feeding efficiency is high with average feed conversion ratios of 1.3:1 (Villarroel, 2003).

TABLE 23
Feeding schedules for catfish, common carp and tilapia, employed by pond farmers in Mexico

Mean fish weight (g)	Catfish		Common carp		Tilapia	
	% body weight/day	Times/day	% body weight/day	Times/day	% body weight/day	Times/day
25	4.0	2	4.5	3	4.5	3
50	3.5	2	4.0	3	3.7	3
75	3.2	2	3.6	3	3.4	3
100	3.0	2	3.3	3	3.2	3
150	2.8	1	3.1	2	3.0	2
200	2.5	1	3.0	2	2.8	2
250	2.2	1	2.6	2	2.5	2
300	2.0	1	2.4	2	2.3	2
400	1.6	1	2.1	2	2.0	2
500	1.4	1	1.7	2	1.7	2
600	1.2	1	1.4	2	1.4	2

Source: Zendejas (2005)

Most of the tilapia, catfish and trout farms in Latin American are semi-intensive and intensive, while carp and indigenous species are generally farmed extensively and semi-intensively. Tilapia are normally fed during the warmest hours of the day between noon and 16:00 hours, irrespective of the culture system (floating cages or ponds). Farmers usually feed once or a maximum of twice a day, using a variety of methods that include delivery by hand, feed blowers, automatic and demand feeders.

Channel catfish *Ictalurus punctatus* farms are intensive and 100 percent dependent on commercial feeds, which are usually provided twice a day during the juvenile stages and once a day during the grow-out stages between 11:00 and 15:00 hours. Sinking pellets are fed using either feed blowers or are manually distributed. Rainbow trout *Oncorhynchus mykiss* are fed floating extruded pellets, either manually (2–4 four times a day) or using automatic feeders (4–6 times a day). Table 23 presents recommended feeding schedules for catfish, common carp and tilapia, as employed by farmers in Mexico.

5.7 Supplementary and other feeds

Farm-made feeds

Farm-made feeds are practically non-existent in the region. A limited number of small-scale farmers in Cuba and Brazil use agricultural by-products including coffee pulp, rice and wheat bran as well as fishmeal, when available, to replace or complement formulated complete diets when these are in short supply or when farm cash flow is problematic.

Farm-made feeds are more common in the ornamental fish industry, regardless of the production scale. A range of nutrient sources are used, ranging from ground, dried shrimp heads to cereals and boiled eggs.

Given the wide range of agricultural and industrial by-products and other potential nutrient sources that are readily available, capacity should be developed and built to formulate and manufacture inexpensive, farm-made feeds using agricultural by-products. This would stimulate rural aquaculture throughout the region and rural development is desperately needed throughout the region.

Use of trash fish

Trash fish is only used as feed in the emerging tuna cage culture industry in Mexico. More than 100 tonnes of tuna is currently produced and the industry is growing fast. Given the exclusive dependence on trash fish and considering an FCR of at least 3:1, then at least 300 tonnes of trash fish is used at current capacity.

6. THE POSSIBLE IMPACT OF FEEDS ON THE SUSTAINABLE DEVELOPMENT OF AQUACULTURE IN LATIN AMERICA

The pattern of growth of the aquaculture industry in Latin America is similar to many parts of the world and is characterized by intensification, increasing number and size of farms and a growing number of cultured species. Consequently, the aquafeed industry in the region has experienced dramatic growth over the past 20 years. On the other hand, the collapse of shrimp production because of diseases in several countries (Ecuador, Mexico and other Central American countries) during the 1980s and 1990s had a hugely negative impact on the aquafeeds industry in the region.

The inter-dependence of feed manufacturers and farmers is the Achilles heel of sustainable aquaculture development in Latin America. Given that the contribution of feed to total production costs has reached levels of 65 percent (Panorama Acuícola, 2007) highlights a number of factors that will impact on the future development of a sustainable aquaculture industry in Latin America. The most important of these are:

6.1 Food safety

Increasing trade of aquaculture inputs and farmed products is prompting governments, farmers and feed manufacturers to adopt quality control measures and traceability programmes to comply with international food safety requirements. This will certainly induce a feedback system of practices that will improve product quality and competitiveness within the sector.

6.2 Price-related factors

Large international corporations have been buying smaller feed manufacturers throughout the region. This has resulted in a regionalisation of markets, reducing local competition, fewer types of feeds and in some instances has resulted in reduced feed quality and higher prices.

6.3 Availability of raw materials

The main protein and lipid ingredients are world trade commodities, the availability of which is dependent upon a series of stochastic factors such as crop success or failure and climatic conditions. These, together with local exchange rates determine the pricing of such ingredients. Prices of raw materials have increased several times in some cases over the past 10 years and are likely to continue increasing, due to recent adverse climatic conditions in major producing countries (e.g. El Niño events in Peru and Ecuador have impacted on fishmeal production). Moreover, global warming and climate change will in future also affect the availability of agricultural commodities. The pressure on fishery resources to produce fishmeal and land surface area to grow increasing volumes of grains to meet a highly demanding industry will certainly compromise the sustainability of the aquaculture sector within the next decade.

6.4 Research on alternative sources of protein

Despite the great biodiversity of the Latin American region research results on potential sources of alternative protein and lipids to replace fishmeal and fish oil are still very modest. This highlights the short sightedness of those large aquaculture corporations that do not invest in research and development. The academic sector lacks the necessary resources to accelerate investigations on the wide spectrum of possible (plant and animal) feed resources to partially or completely replace fishmeal, as well as for example research on improving the nutrient utilization of agricultural and industrial by-products.

6.5 Responsible feeding practices

Although there is a growing tendency for farmers and technical advisors to implement internationally accepted and responsible aquaculture practices, many large farms throughout the region still practise feeding strategies that contribute little to sustainability. Examples of this are the absence of a monitoring scheme of water quality in relation to feeding and the absence of indicators of feed utilization and efficiency. This is a reflection of the lack of structured national responsible aquaculture programmes. Consequently and in many instances, farmer training and adoption of sustainable practices depends exclusively on the technical assistance provided by feed manufacturers and, to a lesser extent, the academic sector of each country. The use of feeding trays in the shrimp industry has become a popular way of reducing feed waste and reducing organic matter and nutrients discharges into the environment. However, it is highly questionable whether the reliance of farmers on feed manufacturers is a healthy situation with respect to the sustainable development of the sector.

6.6 Environmental regulations

The legislative frameworks in relation to sustainable aquaculture development in Latin America are still very weak. Although important advances have been made in relation to habitat modification, organic discharges and movement of exotic aquaculture species, regulations regarding feeds and fertilizers are almost non-existent. Physical properties of feed particles or levels of potentially leaching nutrients are not regulated. However, the pace at which regulations are changing with respect to aquaculture inputs is accelerating in some countries (e.g. Mexico, Brazil and Chile) and this is mainly because of increasing international trade relations, requirements and agreements.

The use of trash fish, although still limited in volume, might escalate as tuna aquaculture expands, especially in Mexico. This could raise several questions regarding quality and competition with human consumption.

6.7 Use of fertilizers

Fertilizers used in aquaculture are in most instances identical to those used in agriculture. This creates a dependency on the local agriculture sectors. Moreover, chemical fertilization is a standard practice in semi-intensive shrimp or fish farms of the region and large quantities of unused nutrients are discharged into the environment. The use of organic fertilizers is gradually decreasing, as the demand for manure in other agricultural sectors increases and consequently prices have reached non-competitive levels.

6.8 Sustainable aquaculture technologies

Use of environmentally sound technologies for aquaculture in Latin America is still incipient, although it is growing. Their use is stimulated by international acceptance and import tax reduction for "organic aquaculture products". Although limited in number, a few commercial farms in Belize, Brazil, Peru and Mexico have adopted zero-water exchange practices, high aeration culture systems. Polyculture and integrated aquaculture have slowly been adopted by farmers in Brazil, Mexico, Peru, Panama and Honduras. Aquaponics is also becoming a popular alternative in small-scale aquaculture in southeast Mexico. Such systems ensure maximum resource utilization and more farmers should be encouraged to adopt a more organic approach to aquaculture in the future.

The use of probiotics, enzymes and immuno-stimulants, as feed additives, or prebiotics applied directly into the water is also still incipient but growing. Some leading farmers have reported encouraging results, particularly in Ecuador (Garriques and Arevalo, 1995).

6.9 Feed manufacturing technologies

Extruded, coated, highly stable feed particles are becoming more common in the aquaculture industry. This directly contributes to lower levels of pollution and higher production rates through improved feed utilization. The use of such feeds must be promoted throughout the region.

7. RECOMMENDATIONS

- Governments should introduce national quality standards for raw materials and feeds as well as for farmed products to strengthen the international competitiveness of national aquaculture sectors, and to provide better quality food for human consumption. This should be done taking into account the present range of culture systems and intensification.
- Research on alternative sources of protein and energy to replace fishmeal and fish oil at least partially, should be encouraged, particularly taking into account the availability of regional resources, including agricultural and industrial by-products. Tax incentives should be granted to feed manufacturers and aquaculture farmers that invest in research and development.
- Levels of phosphorus and other potentially leaching nutrients, as well as digestibility levels of feeds should be regulated to reduce organic pollution in aquaculture discharges or cage sites.
- Aquaculture and agriculture farmers that wish to integrate aquaculture to their traditional agricultural systems are constrained by the high cost of formulated feeds and the lack of basic knowledge on the use of locally available ingredients for the production of low cost, farm-made feeds, which could substantially increase the economic sustainability of rural aquaculture, thus benefiting large sectors of the population. Governments should take cognisance of the opportunities offered by aquaculture for rural development.
- Capacity building of small-scale farmers, particularly with respect to farm-made feeds should be prioritized in aquaculture development plans. A review of locally available potential ingredients is essential, followed by training of extension officers and farmers on basic aquaculture nutrition and farm-made feed preparation. In many cases this will be the only alternative for rural aquaculture to be sustainable.
- Governments should facilitate dialogue between researchers, farmers and feed manufacturers to collectively tackle existing and emerging problems, focus research and to strengthen the competitiveness of the aquaculture sector.
- Improved management of ponds including "ecological management" (i.e. heterotrophic systems) should be promoted to increase system productivity, reduce water use and lower the dependence on high protein, fishmeal-based feeds.

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Review of feeds and fertilizers for sustainable aquaculture development in sub-Saharan Africa

Thomas Hecht
Department of Ichthyology and Fisheries Science
Rhodes University, Grahamstown 6140
South Africa

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SUMMARY

Recent observed changes in production, technological developments and culture practices in sub-Saharan Africa (SSA) have largely been driven by increasing fish prices throughout the region and aquaculture in the region is now poised to increase rapidly. In 2004, Africa as a whole contributed 1.8 percent to world aquaculture fish production, while the SSA region contributed 0.26 percent. Egypt was the largest contributor to African aquaculture (84.5 percent) followed by Nigeria (7.9 percent) and as a whole the SSA region contributed 14.6 percent to African aquaculture output. During the period 2000 to 2004 aquaculture production in SSA increased by 50.8 percent from 54 109 tonnes to 81 598 tonnes. The highest increases in production were recorded in Uganda (575 percent), Cameroon (560 percent) and Kenya (102 percent). Nigeria is the largest producer in the region (43 950 tonnes in 2004), followed by Uganda and Zambia with around 5 000 tonnes each.

This review focuses on seven target countries, namely Cameroon, Ghana, Kenya, Malawi, Nigeria, Uganda and Zambia, and comparative information is provided for other countries in the region. Over 80 percent of fish farmers in the region are small-scale farmers who practise extensive aquaculture on a non-commercial basis to improve household food security. However the bulk of production (~70 percent) is produced by the commercial sector, ranging from small-scale semi-intensive enterprises to industrial scale farming of high value products such as catfish (Nigeria), shrimp (Madagascar and Mozambique) and abalone (South Africa). The most notable developments in the target countries include high density catfish farming in Nigeria, medium and industrial scale cage culture, a switch to commercial aquaculture by previously "non-commercial" farmers (28 percent of farmers in Uganda switched to commercial aquaculture in the last five years), establishment of intensive African catfish hatcheries in Kenya and Uganda, a major expansion of peri-urban aquaculture and dynamic growth in African catfish production.

Between 2000 and 2004 production of clariid catfish had increased by 452% from 5 739 to 31 681 tonnes, contributing 38.8 percent to total SSA production. Over the same period Nile tilapia (*Oreochromis niloticus*) production has increased by 37.2 percent and contributes 25.9 percent to total SSA production. The contribution by common carp (*Cyprinus carpio*) has declined by 11 percent and in 2004 contributed 3.4 percent. The contribution by all other cichlid and non-cichlid species has also declined.

Aquaculture practices are diverse, ranging from single pond subsistence farming to highly intensive pump-ashore abalone farms. The non-commercial sector is characterised largely by the use of "green compost" cribs to enhance pond productivity, irregular application of inadequate quantities of manure and the use of cereal bran, kitchen waste and vegetable matter as feed inputs. Production levels are low (mean = 1.03 tonnes/ha/year) and species choice depends largely on the availability of fingerlings. Commercial, semi-intensive pond culture and intensive cage and tank culture is gaining momentum. Production levels in semi-intensive pond systems are comparable to global averages, ranging from 2.5 to 15 tonnes/ha/year. Polyculture of Nile tilapia and African catfish commonly practised throughout the region, though monoculture is preferred in intensive cage or tank systems. Ornamental fish culture is emerging in several countries.

Except for Uganda and Kenya, the legislative and regulatory environment for aquaculture in the region is weak. It is best developed in Namibia.

There is a clear dichotomy in pond fertilization methods. All non-commercial farmers in the region are constrained either by on-farm availability of manure, price, access, cash resources and transport costs and therefore mainly use compost cribs and some animal manure when available. On the other hand, all commercial farmers, irrespective of scale, use animal manure at appropriate levels and chemical fertilizers where and if necessary, though rarely. Chicken manure is most often used and ranges in price from US$17 to around US$30 per tonne. Animal manure requirement for optimum fish production in

the target countries was estimated based on six possible scenarios. By 2020 total animal manure requirements will be between 257 896 and 754 889 tonnes per annum.

Total animal feed production in the target countries, including South Africa, in 2005 amounted to some 9.0 million tonnes per annum, dominated by South Africa and Nigeria (4.4 and 3.8 million tonnes per annum, respectively). Industrial aquafeeds, manufactured by medium and large scale feed mills, are produced in Cameroon, Kenya, Malawi, Nigeria, South Africa and Zambia, while other countries are on the threshold of commercial aquafeed production. Some 17 000 tonnes of fish pellets and aquafeed mixes were produced in 2005, of which Nigeria produced around 66 percent. The total feed requirement by 2020 was projected based on three growth scenarios of fish production and ranges between 139 000 tonnes and 545 000 tonnes. Only 50–65 percent of the feed milling capacity is utilized and the industry has adequate capacity to provide the needs of the commercial aquaculture sector until 2020.

The general paucity of good quality aquafeeds in the region is generally a factor of scale. In most countries local demand has not reached a critical mass for appropriate attention and investment, though the threshold has now been reached in Nigeria where substantial investments are planned. Only 22 percent of commercial fish production is attributable to industrial aquafeeds. This highlights the pivotal importance of farm-made feeds in the region. Most countries in the region have adequate resources to manufacture appropriate feeds, though the availability and cost of fishmeal and soybean meal or oilseed cake is a major constraint in most countries. The price of feed ingredients, particularly fishmeal, oil seed cakes, soybean meal and maize, is highly variable among countries and varies seasonally within countries. Farm-made feed formulations vary by season, depending on availability and price of ingredients. Some 98 500 tonnes of farm-made feeds are currently produced annually, with reported FCRs ranging from 1.1 to 3.2. In Nigeria some 69.8 percent of fish production is attributable to informal feed manufacturers. There is a good body of knowledge with respect to the proximate composition of locally available feed ingredients and much work has been undertaken on optimal inclusion levels of these ingredients with particular emphasis on fishmeal replacement. The importance of farm-made feeds in the region highlights the urgent and desperate need for further nutritional research in the region.

The principle recommendations emanating from the synthesis include: training of nutritionists and fish feed technologists, developing appropriate manufacturing machinery and bulk storage facilities, evaluating and testing non-conventional feed ingredients, developing databases of available feed and fertilizer resources, developing country specific farm-made feed formulations, effective dissemination of information (availability of ingredients, formulations, manufacturing technologies, feeding schedules), developing country specific animal feed standards and reviewing pertinent legislation to ensure stability, quality and food safety and establishing enabling business environments.

1. INTRODUCTION

In a recent synopsis of sub-Saharan aquaculture the availability, quality, food conversion ratio (FCR) and the high distribution costs of feeds and fertilizers, together with poor quality fingerlings and the general absence of investor friendly regulatory frameworks were singled out as some of the most important issues that constrain the development of commercial and non-commercial aquaculture in the region. It was further concluded that most non-commercial farmers use protein limiting diets, though the use of farm-made feeds is increasing, while locally manufactured feeds, except for isolated cases, are generally of poor quality (Hecht, 2006). This highlights the need for feed quality assurance programmes.

This review focuses, in particular, on the use and availability of feeds and fertilizers for sustainable aquaculture in a select group of sub-Saharan countries and is a sequel to a review undertaken in 2001 (Shipton and Hecht, 2005). The target countries in this instance were Cameroon, Ghana, Kenya, Malawi, Nigeria, Uganda and Zambia. As will be shown later, Cameroon, Uganda and Zambia have recorded the most significant increases in national production while Nigeria remains the giant in the region, though interesting and noteworthy changes have taken place in the other target countries. The most notable changes that have taken place in the last five years are summarized in Table 1. The rapidly escalating price of fish throughout most SSA countries is considered to be the most important driving force of the rapid growth in the sector. For example in Cameroon many previously abandoned ponds have recently been rehabilitated as a consequence of the increasing fish price and this has often been done without technical input from extension services. It was for these reasons that the countries were singled out for this review. For comparison and where appropriate, information on fertilizers and feeds is also presented from elsewhere on the sub continent and from Egypt.

It is currently in vogue to define aquaculture in SSA as being either commercial or non-commercial (Moehl, Halwart and Brummett, 2005). While there is indeed great merit for this distinction these categories are limiting when undertaking a review of feeds and fertilizers for the sustainable development of the sector in the region. In a recent review of SSA aquaculture it was shown that the face of aquaculture throughout the region has and is changing rapidly towards a more commercially orientated activity (Hecht, 2006). "Traditional" low-input/low-output small-holder fish farmers still dominate the scene. However the greater proportion of SSA production is now produced by commercial enterprises that range from small-scale semi-intensive to large industrial scale operations. Therefore, for the purposes of this review, aquaculture in all target countries is categorised by the level of intensity (extensive, semi-intensive, intensive) with respect to culture systems, species cultured, the intensity of management inputs, labour requirements, capital and operational costs, the level of business orientation, the level of integration with other economic on-farm activities such as horticulture or animal husbandry, feeding and fertilization levels. It is not the intention here to define

TABLE 1
Significant developments in sub-Saharan aquaculture since 2000

Uganda	Over 28% of farmers switched to commercial aquaculture in last 5 years. Over 10 intensive African catfish (*Clarias gariepinus*) hatcheries established in last 5 years, now producing around 0.5 million fingerlings per month. Major expansion of African catfish farming.
Kenya	Establishment of six *C. gariepinus* hatcheries, each producing between 10 000 and 50 000 fingerlings per month. Major expansion of catfish farming.
Malawi	Development of a 3 000 tonne cage culture operation in Lake Malawi for production of indigenous chambo *Oreochromis* species (*O. karongae* and *O. shiranus*)
Cameroon	Significant expansion of peri-urban commercial aquaculture
Nigeria	Development of high density clariid catfish culture, rapid expansion of urban aquaculture.
Ghana	Developments in Nile tilapia (*O. niloticus*) cage culture.

Source: Hecht (2006)

TABLE 2
Characteristics of the aquaculture sector in sub-Saharan Africa

CATEGORIES and CHARACTERISTICS	Extensive	Semi-intensive	Intensive
Culture systems	Earthen ponds	Earthen ponds and cages	Cages, raceways, tanks and earthen ponds
Species	Polyculture (various tilapiine species, catfish and carp)	Mainly polyculture (Nile tilapia and African catfish), some monoculture (tilapia)	Mainly monoculture
Management input	Low to medium	Medium to high	High
Labour needs	Family labour to low requirement for external labour	Medium	Low to high (more capital intensive)
Capital costs	Low to medium	Medium	Medium to high
Operational costs	Zero to low	Medium	High
Business orientation	Low to medium	Medium to high	High
Integration with other farm activities	Medium to high	Low to high	Low
Feeding	Zero to supplementary	Scheduled to unscheduled using mainly farm-made feeds	Scheduled intensive feeding using pellets or farm-made feeds
Fertilisation	Zero to medium level	Medium to high level	Zero to high level

Source: Author's data and country reviews

the various categories, but simply to highlight the diverse nature of the sector and to make the point that these categories better facilitate a review of the current situation with respect to feeds and fertilizers. These categories and their general characteristics are summarized in Table 2. Non-commercial farmers as per the definition of Moehl, Halwart and Brummett (2005) would normally, but not exclusively, practice extensive fish farming.

Except for experimental shrimp (*Penaeus* species) culture in Kenya, mariculture is not practiced in any of the maritime countries considered here. Brackish-water aquaculture is practiced only in Nigeria and at a low level. Mariculture in SSA is restricted mainly to shrimp culture in Madagascar, Mozambique and Seychelles and abalone aquaculture in South Africa. Therefore the review focuses mainly on inland freshwater aquaculture. The analysis is based mainly on country reviews for Cameroon (Pouomogne, 2007), Ghana (unpublished reports by Abban, 2005 and Hasan, 2005), Kenya (Nyandat, 2007), Malawi (Chimatiro and Chirwa, 2007), Nigeria (Ayinla, 2007), Uganda (Rutaisire, 2007) and Zambia (author's data) and a review of the primary and grey literature and government reports. For the purposes of this review sub-Saharan Africa includes all continental sub-Saharan countries and Madagascar. Production statistics extracted from Fishstat (FAO, 2006) for comparative purposes and with which to put SSA aquaculture into perspective includes only data for species that depend on feeds and fertilizers.

2. GENERAL OVERVIEW OF AQUACULTURE, FARMING PRACTICES AND SYSTEMS

Aquaculture in sub-Saharan Africa contributes 0.26 percent and 14.6 percent to total World and African aquaculture production, respectively (FAO, 2006). Nigeria with a production of over 43 950 tonnes per annum in 2004 is by far the largest producer in SSA, though this figure still falls far short of the 471 535 tonnes produced by Egypt in 2004. Nevertheless, since 1990 there have been substantial increases in production in many of the SSA countries (Figure 1). For the SSA region as a whole total production had increased by 434 percent between 1990 and 2004, while in the target countries production had increased by 436 percent. During the last 5 years (2000–2004) production in SSA has increased by 50.8 percent from 54 109 to 81 598 tonnes and in the target countries by 56.4 percent from 36 870 to 57 662 tonnes. In 2994 Nigeria

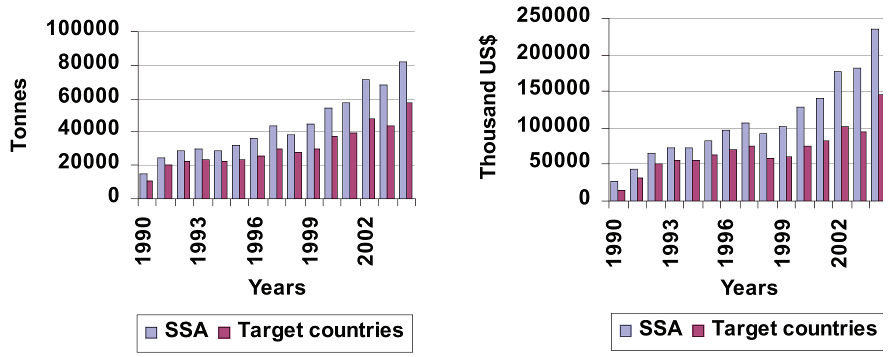
TABLE 3
Total aquaculture production (tonnes) by country

Country	2000	2001	2002	2003	2004	2005	Percent increase
Cameroon	50	150	330	320	330	820	560
Ghana	*	*	*	938	950		
Kenya	512	1 009	798	1 012	1 035		102
Malawi	530	568	642	666	733	800	38
Nigeria	25 718	24 398	30 663	30 677	43 950		71
Uganda	820	2 360	4 915	5 500	5 539		575
Zambia	4 240	4 520	4 630	4 501	5 125		21
Target countries	36 870	39 005	47 978	43 614	57 662		56
SSA	54 109	57 562	71 802	68 121	81 598		51

*Excluded because of questionable data

Source: FAO (2006) and country reviews

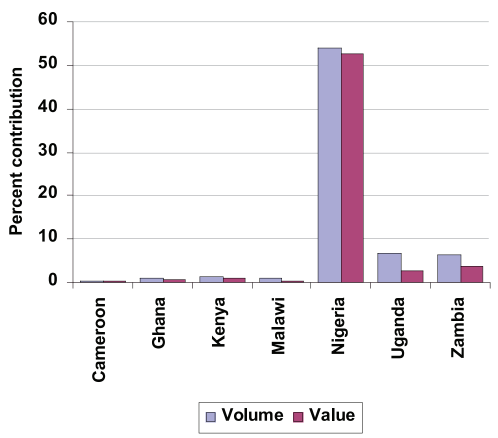
FIGURE 1
Aquaculture production by volume (left) and value (right) in SSA and target countries for the period 1990 – 2004



Source: FAO (2006)

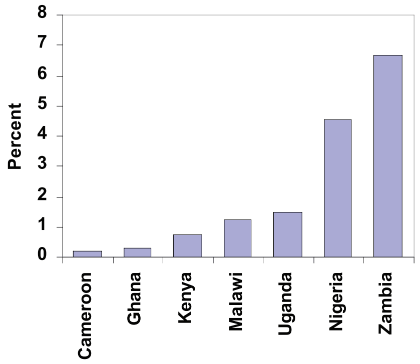
produced approximately 53.9 percent of the SSA total, while Uganda and Zambia each contributed ca. 6.5 percent. Other target countries contributed between 0.4 and 1.2 percent to the 2004 SSA total (Figure 2). In terms of value Nigeria is the only SSA country for which the percent value approximates the value for volume and this is most likely because of the high price of fish in Nigeria (up to US$4.50/kg in urban areas – Hecht, 2006). While Nigeria is clearly the giant in the region, production over the last 5 years had only increased by 71 percent, in comparison to increases of 575 percent, 560 and 102 percent recorded for Uganda, Cameroon and Kenya, respectively (FAO, 2006). However, between 2003 and 2004 production in Nigeria has jumped from 30 677 tonnes to 43 950 tonnes. This clearly illustrates the pace of development of the sector in Nigeria in relation other SSA countries. Despite these impressive increases aquaculture in 2004 only made a measurable contribution to national fish supply (sum of capture fisheries, aquaculture and imports) in Malawi (1.25 percent), Uganda (1.5 percent), Nigeria (4.5 percent) and Zambia (6.7 percent), while in the remainder of the target countries

FIGURE 2
Percent contribution by target countries to total SSA production, volume and value



Source: FAO (2006)

FIGURE 3
Aquaculture production as percent of total fish supply in 2004



Source: FAO (2006) and www.earthtrends.com

the contribution was less than 1 percent (Figure 3). The contribution made by aquaculture to GDP in the target countries is insignificant, ranging from 0.005 percent for Cameroon to 0.154 in Nigeria (Hecht, 2006). However, aquaculture where practiced, makes a significant contribution to food security in rural areas. Table 3 summarizes the most recent production figures for the target countries.

Small-scale non-commercial fish farmers vastly outnumber commercial farming enterprises. Using information provided in the NASOs (National Aquaculture Sector Overviews) (FAO Fisheries Global Information System, 2006) of the target countries, which formed the basis of the review of aquaculture in SSA (Hecht, 2006) and the country reviews on feeds and fertilizers it was possible to obtain a rough estimate of the number of non-commercial and commercial farmers and the size of the operations (Table 4). Non-commercial farmers account for around 80 percent of the total number of fish farmers.

However, the bulk of production is produced by the commercial sector (Table 5). The data suggest that 70.5 percent of fish in the target countries was produced by the commercial sector. Of course this estimate is highly skewed by the size and output of the commercial sector in Nigeria. Nevertheless, it shows that commercial aquaculture in SSA, despite the constraints with respect to the availability of commercially produced formulated pellets, is gaining momentum.

TABLE 4
Number of fish farming operations in target countries

Country	Number of Non-commercial farmers	Number and type of commercial enterprises	Size of commercia enterprises	Total area (ha) under culture (commercial and non-commercial)
Cameroon	ca. 3 200	2 large earthen pond farms	Unspecified	270
		400–800 peri-urban earth pond farms	Approx. 0.5 ha	
Ghana*	ca. 800	1 cage culture operation	10 cages (15 m dia x 6 m)	154
		4 earthen pond farms	Pond farms (3.1 to 10 ha)	
Kenya	5 890	1 tilapia tank farm	Unspecified	419
		3 rainbow trout raceway/tank farms	Unspecified	
		Cage farms	Unspecified	
		6 catfish hatcheries		
Malawi	4 050	1 rainbow trout tank farm	0.5 ha	269
		1 cage operation	32 x16 m diameter cages under development 12 ha	
		1 pond farm		
Nigeria	50 000	>2600 earthen pond and tank farms	Unspecified	60 000
Uganda	8 000	11 catfish hatcheries		1 200
		Several pond farms	Unspecified	
Zambia	6 000	4 cage farms	44 cages (6x6x3 m) and 10 pens	260
		10 pond farms	Total pond area = 195 ha	

*Two of these farms (one cage culture and one earthen pond) produce >50% of Ghana's aquaculture output (Hasan, 2005)

Source: Country reviews

TABLE 5
Estimates of commercial production (tonnes) in target countries

COUNTRY	Year	% of fish from commercial farms	Total production	Commercial production
Cameroon	2004	8%	650	52
Ghana	2004	32%	950	304
Kenya	2003	100% of trout, 15% of tilapia 85% of catfish	29 600 319	29 90 271
Malawi	2003	100% of trout 11% of other fish	15 651	15 72
Nigeria	2004	80%	43 950	35 160
Uganda	2003	40% (projected 60% in 2005)	5 500	2 200
Zambia	2003	75%	4 501	3 376
TOTAL			**53 951**	**40 736**

Source: FAO (2005), Hecht (2006) and modified using data provided in country reviews

3. THE SPECIES

Approximately 27 species are farmed in the seven target countries (Table 6). Table 7 provides a summary overview of the most import species groups, with particular reference to Nile tilapia (*Oreochromis niloticus*), African catfish (*Clarias gariepinus*) and common

TABLE 6
Aquaculture species in target countries

SPECIES	Cameroon	Ghana	Kenya	Malawi	Nigeria	Uganda	Zambia
Cichlidae							
Nile tilapia *(Oreochromis niloticus)*	x	x	x		x	x	x
Mozambique tilapia *(O. mossambicus)*				x			
Three spotted tilapia *(O. andersonii)*							x
Longfin tilapia *(O. macrochir)*							x
Chambo *(O. shiranus shiranus)*				x			
Chambo *(O. karongae)*				x			
Banded jewel fish *(Hemichromis fasciatus)*	x						
Redbelly tilapia *(Tilapia zillii)*						x	
Redbreast tilapia *(T. rendalli)*				x			x
T. guineensis		x					
Blackchin tilapia *(Sarotherodon melanotheron melanotheron)*		x					
Mango tilapia *(Sarotherodon galilaeus galilaeus)*	x	x					x
Clariidae							
North African catfish *(Clarias gariepinus)*	x	x	x	x		x	x
Vundu *(Heterobranchus longifilis)*							
Hybrid catfish*							
Cyprinidae							
Common carp *(Cyprinus carpio)*	x	x	x	x	x	x	x
Silver carp *(Hypophthalmychthys molitrix)*					x		x
Grass carp *(Ctenopharyngodon idella)*					x		x
Others							
African bonytongue *(Heterotis niloticus)*	x	x			x		
Snake-head *(Parachanna obscura*)	x				x		
Kafue pike *(Hepsetus odoe)*				x			
Rainbow trout *(Oncorhynchus mykiss)*			x	x			
Squeaker *(Synodontis sp.)*					x		
Nile perch *(Lates niloticus)*					x		
Aba *(Gymnarchus niloticus)*					x		
Distichodus *(Distichodus sp.)*					x		
Moon fish *(Citharinus sp.)*					x		

**Clarias gariepinus x Heterobranchus longifilis (or H. bidorsalis)*

Source: Country reviews, FAO Fisheries Global Information System (2006) and FAO (2006)

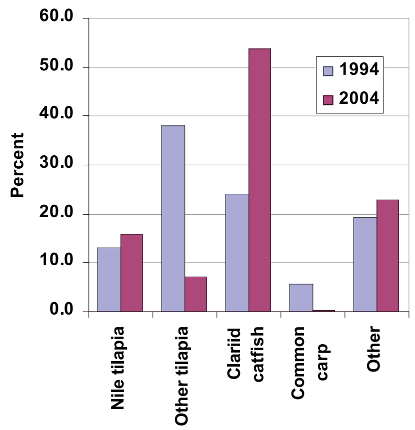
TABLE 7
Production in 2004 by species groups in tonnes and percent contribution

Country	Nile tilapia	Other tilapia	Clariid catfish	Common carp	Others	Total
Cameroon	210		114	6		330
Ghana	760				190	950
Kenya	614		320	67	34	1 035
Malawi		697	17	4	15	733
Nigeria	3 000	1 176	26 750	44	12 980	43 950
Uganda	1 660		3 827	50	2	5 539
Zambia	2 900	2 180		45		5 125
Total	**9 144**	**4 053**	**31 028**	**216**	**13 221**	**57 662**
Percent of total	**15.9**	**7.0**	**53.8**	**0.4**	**22.9**	

Source: FAO (2006)

carp (*Cyprinus carpio*). In most countries except Malawi and Zambia, *O. niloticus* is the dominant cichlid produced in aquaculture. Malawi has managed to exclude *O. niloticus* from its waters and in Zambia greenhead tilapia (*O. machrochir)* accounts for over 41 percent of production, while *O. niloticus* accounts for 35 percent of total production. The farming and production of *Cyprinus carpio* and indigenous cichlids has declined throughout the SSA region during the last decade, while the production of *C. gariepinus*, in particular, as well as *O. niloticus* has increased significantly (Figure 4). Between 1999 and 2004 common carp production throughout SSA has declined by 11 percent. The reasons for the decline are unclear but may be related to consumer preferences and fish price.

FIGURE 4
The change in percent contribution to total production by species groups in the target countries between 1994 and 2004



4. AQUACULTURE PRACTICES AND THE FARMING SYSTEMS

The diversity of farming systems in the region varies according to the motivation and circumstances of the farmers. Non-commercial fish farmers in all target countries practise extensive aquaculture and normally own between 1 and 5 small ponds (average = 2 ponds), ranging from 100 to 350m^2. Ponds are either situated on the farmers own land or are clustered in fish farming "clubs" (Figure 5).

Diversion ponds are most commonly used, though in some instances (Malawi, Cameroon, Ghana) ground water seepage ponds are also often used by small-holder fish farmers. Production technologies are characterised typically by the low level of inputs resulting in low yield. Annual production by non commercial farmers in the target countries ranges from 0.5 to 2.5 tonnes/ha/year and averages around 1.2 tonnes/ha/year. Most of the fish produced on non-commercial farms is internalised, used for

FIGURE 5
Typical small-holder farm pond (left) and club ponds (right)

barter and cash income and plays a significant role in food security at the household level. Most farmers in this category use "green compost" cribs and occasionally use animal manure when available (chicken, goat, rabbit and cattle manure) to enhance natural pond productivity and use cereal bran (maize, rice and wheat), kitchen waste, green leaves and non-conventional animal protein products as feed, when available. Substantial proportions of farmers in all target countries do not provide any pond inputs and rely only on natural pond productivity. In Cameroon the cribs comprise around 10 percent of pond surface area, though in other countries may comprise less than 1 percent of the pond surface. Most farmers practise some form of arbitrary polyculture, which is largely dependent on the availability of fingerlings. Because of higher yields, polyculture of *O.niloticus* (or other Tilapia species (e.g. *O.shiranus* and *O.mossambicus* in Malawi and *O.andersonii* in Zambia) with *C.gariepinus* or other clariid species, such as *Heterobranchus* spp. is becoming the most preferred practice even by non-commercial farmers, particularly in Nigeria as well as in Cameroon, Ghana, and Uganda.

Stocking densities remain low, at an average of 1–4 fingerlings/m^2. Fishponds are usually stocked using fingerlings left over at harvest or purchased from neighbours. More often than not, this means that small mature fish (stunted) that have no or very little scope for growth are stocked as fingerlings. Some farmers stock their ponds with fingerlings captured from rivers, lakes or wetlands and this leads to higher yields (ADiM, 2005).

Management practices by the majority of non-commercial farmers in all target countries, with respect to scheduled stocking, fertilization, feeding and harvesting is rudimentary, except where farmers work in collaboration with development projects. Labour on most non-commercial fish farms is provided by the family, though hired labour is used where this is affordable. Many small-scale farmers do not have the cash or other resources to hire labour and this is a major constraint on small-holder farms. In Cameroon, Kenya, Malawi, Uganda and Zambia most small-scale fish farmers have integrated their fish farming activities with agriculture in one or several ways. Though not mentioned in the country reports it is assumed that the same holds true for Ghana and Nigeria.

Semi-intensive and intensive commercial aquaculture except in Nigeria and Zambia, where it is relatively well established, is a rapidly emerging activity in all target countries. The sub-sector has gained particular momentum in the last five years. As mentioned previously these developments are principally ascribed to the rapidly escalating fish price in peri-urban and urban areas as well as to progressive changes in government policy and support for the private sector, particularly in Kenya and Uganda (Hecht, 2006 and see SSA country reports). In 2004 the average price of fish in peri-urban and urban markets was US$2.5/kg (US$1.6 in Kenya to US$4.5/kg in Nigeria). The adoption and implementation of strategic aquaculture development plans also act as enabling tools for the development of the sector (Hecht, 2006). Strategic plans have now been adopted in Cameroon, Zambia and Malawi, awaiting adoption in Nigeria and in a preparatory phase in Ghana. Most importantly, these developments have improved investor confidence in the sector in all target countries. Nevertheless, as suggested by Hecht (2006), there is an urgent need to educate financial institutions in all SSA countries as to the potential, risks and benefits of commercial aquaculture, such that they are better equipped to assist the development of the sector.

There is a wide spectrum of commercial fish farms in SSA that range from small to medium scale operations in peri-urban areas, to large pond and or cage farming operations. The level of intensification in each of these categories ranges widely from semi-intensive pond culture, to small and large cage culture operations to high density tank culture of African catfish, using water recirculation technology (Figures 6–10). It is clear from the country reviews that each system has evolved and is driven by market needs. For instance, limited by space, urban and peri-urban farmers in Nigeria are using recirculation technology (Figures 9 and 10), while farmers in Uganda and Kenya have recognized the opportunities provided by the Nile perch longline fishery in Lake Victoria for the supply of live African catfish fingerlings as livebait and have therefore become full-time fingerling producers (Figure 11).

Except for Uganda and Kenya, the legislative and regulatory environment in the other countries remains weak and does not actively promote investment in the sector. Where these shortcomings exist (Cameroon, Ghana, Malawi, Nigeria and Zambia) the problem has been recognized and is being addressed through the development of strategic sector development plans (Hecht, 2006).

Production by commercial enterprises is variable and depends on the systems employed and the level of intensification. Cage culture production levels in Ghana, Zimbabwe and Zambia with *O.niloticus* range from 2 to 4 tonnes/100 m^3. Cages range from small locally made cages to medium size square cages (6x6x3m), to 796 m^3 in Ghana to 1 200 m^3 circular cages (Malawi). The largest cage culture operation in SSA is Lake Harvest (Pty) Ltd (Lake Kariba, Zimbabwe), producing around 2 500 to 3 000 tonnes per annum, most of which is exported to the European Union (EU). A similar operation is now being established in Malawi. The Malawian operation intends to produce 3 000 tonnes of chambo, *O. karongae* or

FIGURE 6
Emerging small-scale commercial farmers specialising in fingerling production (left) and table fish production (right)

FIGURE 7
Large scale polyculture pond farming of *C. carpio, C. gariepinus* and *O. mossambicus*

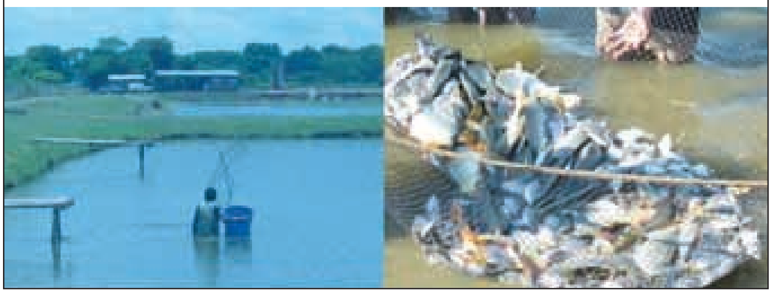
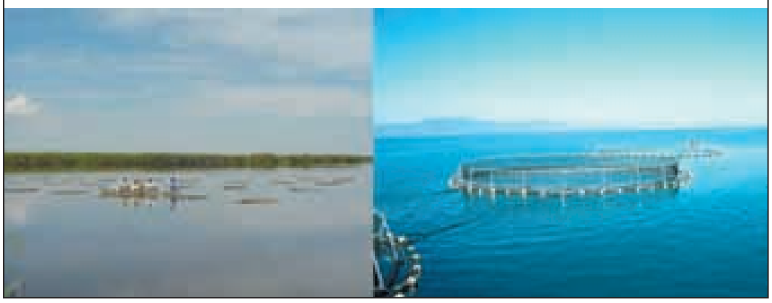


FIGURE 8
Small Nile tilapia **cages in Lake Kanyaboli in Kenya (left) and large *chambo* cages in Lake Malawi (right)**



COURTESY OF M. MBUGUA

FIGURE 9
Trickle filter tower (left) and high density indoor rearing tank (right) at an African catfish farm in Nigeria

COURTESY OF MOHAMMAD R.HASAN

FIGURE 10
African catfish broodstock and recirculating hatchery in Nigeria

COURTESY OF K.J. RANA

FIGURE 11
***Clarias gariepinus* hatchery in Uganda**

COURTESY OF J. RUTAISIRE

FIGURE 12
Circular and D-ended *O. niloticus* tank farm in Kenya

O. shiranus in 32 cages in Lake Malawi. Initial stocking density ranges from 65 to 75 fingerlings (30g average weight) per m^3. Final biomass at harvest ranges from 21 to 40 kg/m^3 after growth cycles of 6 to 9 months.

Commercial aquaculture in earthen ponds is well developed in Nigeria and Zambia. In many of the target countries polyculture of *O. niloticus* and *C. gariepinus* is currently the most popular practice, though some farmers use other combinations. While polyculture is practised in all countries commercial farmers in several countries also produce *O. niloticus* (Zambia and Kenya) and *C. gariepinus* (Nigeria) under monoculture farming conditions. Production levels range from 2.5 to 15 tonnes/ha/year for *O. niloticus* (monoculture) and *O. niloticus*/*C. gariepinus* polyculture and up to 10–30 tonnes/ha/year for *C. gariepinus* monoculture in Nigeria. The size of production ponds ranges from 500 m^2 to 1.5 ha. Stocking densities in earthen ponds average around 5 to 8 fingerlings per square meter.

High density mono-culture of *C. gariepinus* in tanks (using water recirculation) is expanding rapidly in Nigeria, particularly in urban and peri-urban areas. Final densities as high as 100 kg/m^3 have been reported and initial stocking densities may be as high as 50 fingerlings/m^2. Some of the high density farms in Nigeria now produce in the region of 3 tonnes of catfish per week. In response to the demand by the Nile perch long line fishery in Lake Victoria, farmers in Uganda and Kenya have developed intensive hatchery and fingerling rearing technologies. In Kenya there are six and in Uganda there are eleven commercial catfish hatcheries. These hatcheries supply the Nile perch fishery with live fingerlings of around 10 g and also supply other farmers with catfish fingerlings for grow-out. The capacity of the Ugandan and Kenyan catfish hatchery operators ranges from 10 000 to 30 000 fingerlings per month. It is not known how many catfish hatcheries there are in Nigeria, nor is there an accurate figure for the number of high density catfish farms.

Concrete raceways are the preferred mode of rainbow trout production in Malawi and Kenya. Circular and D-ended concrete tanks are also used for the production of *O. niloticus* in Kenya (Figure 12) and Zambia.

Cameroon, Uganda, Kenya, Malawi and Zambia also boast an emerging ornamental fish farming sector, which produces fish for the local as well as the export market. Ornamentals are produced in concrete tanks and earthen ponds. The volumes and or numbers produced are not known.

5. REVIEW AND ANALYSIS OF FERTILIZER USE IN POND AQUACULTURE

Pond fertilization practices and the use of different commodities to enhance pond productivity in the region are very diverse and depend to a large extent on the scale of operation. Table 8 summarizes the types of fertilizers used by commercial and non-commercial farmers in the target countries. Compost cribs are not used by commercial farmers and chemical fertilizers are only used by commercial farmers and then only when these are available. Similarly, manure is only used intermittently by non-commercial farmers, when available.

The vast majority of small-scale, non-commercial farmers use "green compost cribs" to fertilize their ponds. In many instances this is supplemented by animal manure, though there is no evidence to suggest that farmers adhere to any fixed fertilization regimen. Depending on the resource base of the farmer some only fertilize their ponds at irregular intervals and do not provide supplementary feeds. This practice has been recorded in Kenya, Zambia, Malawi and Uganda and no doubt also occurs in the other target countries. The size of the compost crib varies substantially. In Cameroon the cribs comprise an average of 10 percent of pond surface area to less than 1 percent (personal observations in Malawi and Zambia). Kitchen wastes and other agricultural by-products are also often dumped into the cribs. The general recommendation throughout the region is that the contents of the crib should be turned once every one to two weeks (Figure13). It is however not known to what extent this is practiced.

Emerging commercial farmers in Cameroon, Ghana, Nigeria and Uganda often still use a combination of crib and animal manure fertilization. However, as soon as they can afford adequate quantities of animal manure they no longer use the crib technique.

The most commonly used manures are chicken, pig (depending on the religious persuasion of the region and of the market) and cattle manure, though the prevalence of use varies among countries. For example in Uganda most farmers (58 percent) use cattle manure, while chicken manure was least used. In Malawi, Nigeria, Ghana and Cameroon chicken manure is most commonly used. Other less often used manures include goat, sheep, duck and rabbit manure. Chicken manure appears to be readily available in all countries. In Cameroon, Ghana, Malawi and Uganda it is either available free of charge or at a minimum cost from industrial broiler farms. However, the cost of bagging and transport is often such that non-commercial farmers cannot afford

TABLE 8

Use of compost, manure and inorganic fertilizers by non-commercial (NC) and commercial (C) fish farmers in target countries

Country	Compost		Manure		Fertilizers	
	NC	C	NC	C	NC	C
Cameroon	Yes	No	Yes	Yes	No	NPK (20:10:10), though rarely used
Ghana	Yes	No	Yes	Yes	No	NPK though rarely used
Kenya	Yes	No	Yes	Yes	No	NPK, under semi-intensive conditions
Malawi	Yes	No	Yes	Yes	No	TSP, NPK, urea (used only occasionally and in combination with animal manure)
Nigeria	Yes	No	Yes	Yes	No	SP, TSP, NPK used only occasionally and in combination with manure.
Uganda	Yes	No	Yes	Yes	No	DAP, NPK, urea and phosphoric acid used mainly to start plankton blooms in catfish fingerling ponds.
Zambia	Yes	No	Yes	Yes	No	TSP, NPK

NPK = nitrogen, phosphorus and potassium; TSP = triple super phosphate; SSP = single super phosphate; DAP = di-ammonium phosphate.

Source: country reviews

the commodity. Moreover, in most countries there is considerable competition from vegetable farmers for chicken manure. Pig and cattle manure is apparently only used in instances where the animals are kept in a kraal (enclosure) during the night to facilitate collection. The practice of holding animals in pens above the ponds or in enclosures adjacent to the pond is also increasing. The average density at which chickens and pigs are kept for fish pond fertilization is 1 to 2 pigs (>25 kg) or 50 mature birds per 100 m^2. It is well known that semi-intensive duck cum fish farming has been promoted by development partners and is practiced in several countries in SSA. It was however not mentioned in any of the country reports. This may indicate that the practice is not popular, practical or profitable.

There is no doubt that adequate quantities of manure are produced in each country to satisfy the requirements of agriculture and aquaculture. For instance, total manure production in Cameroon and Kenya amounts to 30 000 and 18 788 tonnes per annum, respectively (Pouomogne, 2007 and Nyandat (2007). Similar calculations using livestock production figures from the various target countries would undoubtedly also show that manure is available in adequate quantities. However, the costs involved in collecting, bagging and transport prohibits its ready use by fish farmers. In summary, it can be concluded that on a national basis adequate quantities of manure are available in all countries. However, the low livestock holdings of small-holder farmers, or alternatively the high cost of acquisition limits its use in non-commercial aquaculture throughout the region.

The use of animal manure in small-holder aquaculture is further constrained by free range farming practices and the limited number of livestock kept by farmers. For example, in Malawi the average number of livestock per fish farming household is around 4 chickens and 1 goat. Using on-farm livestock population estimates it was calculated that small-holder farmers in Malawi have access to about 2.6 tonnes of wet manure or 1.62 tonne of dry manure per annum. This quantity is not sufficient for the production of the main food crop (maize), which requires about 12.5 tonnes/ha, hence very little if any is left for fish production. In Uganda it was estimated that more than 80 percent of fish farmers have access to fertilizers (all types) all year round but not in sufficient quantities. No doubt the same holds true for small-holder, non-commercial farmers in other target countries.

Manure is either spread directly over the water or is incorporated into the crib or is allowed to leach from grain bags that are tied to a stake in the centre or the side of the pond. All of the target countries have aquaculture extension services of one kind or another (Hecht, 2006), which for many years have been promoting basic aquaculture and pond management techniques to small-holder farmers. Hence, while farmers may understand the need for drying out their ponds after harvest and fertilization with animal manure prior to filling and stocking, very few farmers actually practice these basic techniques. The reasons for this are manifold but are also clearly related to on-farm labour requirements for other economic activities and the need to adhere to the agricultural calendar. Many small scale fish farmers in Malawi, Uganda, Kenya, Cameroon and Ghana consider fish as a "free extra" and many farmers rely solely on natural productivity to obtain a small but welcome intermittent harvest. In other words, aquaculture is of a lower priority than staple food production.

Recommended initial manure application rates in the target countries are similar and range from an initial start up fertilization regimen of 50–60 kg for chicken manure, 50–65 kg for pig manure and 70–150 kg/100m^2 for cattle manure, with follow up rates of 6, 7 and 8–9 kg for chicken, pig and cattle manure respectively per 100 m^2 every 10–14 days. However, in Cameroon (Pouomogne, 2007) and Ghana (Abban, 2005), and no doubt elsewhere actual application rates are far below (<30 percent) the recommended rates. In Malawi, Brummett (1994) calculated that only 27 percent of the nitrogen requirements of ponds are met by the average fertilization rates, which is reflected by the low yields.

FIGURE 13
Mixing of compost crib in Cameroon (left) and mechanical application of cattle manure in Zambia (right)

COURTESY OF V. POUOMOGNE

It is clear from the country reviews and Hecht (2006) that commercial fish farmers follow more rigid pond management regimens, with respect to drying, liming and adequate fertilization throughout the production cycle. Crude Secchi disks are now quite commonly used by emerging commercial farmers to gauge the need for fertilization in Cameroon, Ghana, Uganda and Malawi. The most commonly used manures by commercial farmers are chicken, cattle and pig manure (depending on availability and cost). Many of the larger commercial fish farms have integrated fish production with other forms of animal husbandry. For example, one of the larger fish farms in Zambia relies on manure from the farms cattle herd (Figure 13) and some larger chicken farmers in Uganda, Zambia and Nigeria have expanded their activities to include fish farming.

Inorganic fertilizer is used only by some commercial farmers and then mostly to “kick start” pond productivity, which is thereafter maintained by the application of animal manure. Several catfish fingerling producers in Uganda use only chemical fertilizer (phosphoric acid and urea) with which to enhance pond productivity. The price of inorganic and organic fertilizers in the target countries in 2004/5 is illustrated in Table 9.

The data show that the average farm gate price of animal manure is substantially lower than the average price of chemical fertilizers. However, while animal manure is significantly cheaper per tonne than inorganic fertilizer, the quantities required and the cost of transport makes it unaffordable to most small-holder farmers. In Malawi and Uganda (for which data were available) the cost of transport ranges from US$0.5 to 1.11 km/tonne. If a farmer is located 50 km form the nearest chicken farm effectively trebles the cost, unless purchased and transported in bulk (7 to 10 tonnes per trip). Using the price of chicken manure and the average price of chemical fertilizers in Uganda and Malawi and the theoretical quantities of manure required to 1 ha of fish ponds on a yearly basis in relation to super phosphate makes the former three times more expensive than the latter. The Malawi report revealed that 75 percent of small-holder farmers cannot afford to purchase adequate quantities of fertilizer for their annual maize crop. It stands to reason therefore that they would be even less able to

TABLE 9
Price of fertilizers and manure in target countries in 2004/5 (US$ per tonne)

Chemical fertilizers	Cameroon	Ghana	Kenya	Malawi	Nigeria	Uganda	Zambia
Triple super phosphate			470				
NPK		402		340	600		
Urea		468	440				
Di-ammonium phosphate			500				
CAN			400				
Average chemical fertilizer price	272–400	435	452.5	368.7	-	430–500	383
Manure							
Chicken manure	74	11*–22	54	26.9	29	16.6	22
Cattle manure	45		130	4	18		10
Pig manure	45		60				

* Poultry farm gate price

Source: Country reviews, Hasan (2005) and B. Thiga, Sagana Aquaculture Centre, Kenya, (pers. comm.)

afford the cost of adequate manure (if they have to purchase it) for the fertilization of fish ponds. In a survey conducted in 2004 it was found that only 9 percent of farmers applied adequate amounts of fertilizer to their ponds and over 63 percent did not apply any fertilizer at all. The picture with respect to manuring of crops was very similar, with only 9 percent of farmers applying adequate quantities, 56 percent under applying and 21 percent not applying any fertilizer at all (Singa, 2004). Similarly, in Uganda farmers are all aware of the value of animal manure and many purchase some quantities but cannot afford adequate amounts.

From this we may conclude that the cost of adequate quantities of manure to effectively boost fish production is too high for the average non-commercial fish farmer in the region. This conclusion is corroborated by the fact that the majority of small-holder, non-commercial fish farmers use green compost cribs as the primary method of fertilization. Unless there is a change in this dynamic it will not be possible for small-holder farmers to make meaningful contributions to national fish supply. However, the important contribution by fish ponds to household protein supply should not be underestimated in rural areas.

6. REVIEW AND ANALYSIS OF FEEDS AND FEEDING

Analysis of the country reports revealed that commercial aquafeeds in 2005 were only manufactured in Cameroon, Kenya, Malawi (non pelleted feed mix), Nigeria and Zambia, though initiatives are now also underway to produce fish pellets in Ghana and Uganda. Approximately 12 000 tonnes of commercial fish feed was manufactured in the five target countries, of which the bulk (88 percent) was produced in Nigeria. The types of feeds produced are shown in Table 10. Perhaps most importantly the summarized information in Table 9 illustrates the pivotal role of farm-made feeds[1]. Given the total volume of fish produced and the proportion produced by commercial farmers (see Table 4) it is fair to conclude that the aquaculture sector relies almost entirely on farm-made feeds. On the assumption that country production statistics are realistic crude calculations using a food conversion ratio of 1.8:1, suggests that the commercial aquafeed produced by the formal industry accounts for a maximum of 15.6 percent of total fish production in the target countries or 22 percent of fish produced by the commercial aquaculture sector.

A wide range of ingredients are available for feeding fish and or for the manufacture of fish feeds in the region. Table 11 lists some of the ingredients commonly used by feed manufacturers (formal and informal) and based on information provided in the

TABLE 10
Species and use of commercial and or farm-made feeds in sub-Saharan Africa

FEEDS	Cameroon	Ghana	Kenya	Malawi	Nigeria	Uganda*	Zambia
Trout							
Commercial			√				
Farm-made			√	√			
Tilapia							
Commercial	√		√		√		√
Farm-made	√	√	√	√	√	√	√
Catfish							
Commercial					√ and**	**	
Farm-made	√	√	√	√	√	√	√
Common carp							
Commercial							
Farm-made	√	√	√	√	√	√	√
Ornamental							
Commercial			√				
Farm-made	√		√	√		√	√

*Two firms are currently undertaking fish feed manufacturing trials; **Imports from Aquanutro (Pty) Ltd, South Africa and elsewhere

[1] Farm-made feeds collectively describes fish feeds made by farmers as well as by informal small-scale feed manufacturers.

TABLE 11
Availability of the most common ingredients for the manufacture of animal feeds in sub-Saharan Africa

Commodity	Cameroon	Ghana	Kenya	Malawi	Nigeria	Uganda	Zambia
PLANT ORIGIN							
Coffee pulp	++		++	+	+		++
Cacao husks	+++		-	-	++		-
Rice ban	+	++	++	++	+++	+++	++
Wheat bran	++	+	++	+	++	++	++
Maize bran	+++	++	++	+++	+++	+++	+++
Groundnut bran	?	++	?	?	?	?	?
Wheat pollard	?	?	++	?	?	?	?
Maize	++	+	+	++	++	++	++
Millet	+		+	+	+		+
Soybean	?	+	+	+	+	+	+
Wheat	+		+	+	++	+	+
Oil seed cakes							
Cotton	++	++	+		+++	++	+
Groundnut	+	++	++	+	++		+
Sunflower	?		++	++	+	++	++
Palm kernel	++		-	-	++		-
Soybean	+++		+	+	+	+	+
Copra	?	++	+	-	?		-
Sesame	?		+	-	+		-
Other seed cakes		++				++	
Brewery waste	++	++	++	++	++	++	++
Vegetable oils	+++	++	+	++	+++	++	+++
ANIMAL ORIGIN							
Fishmeal (local)	+	+	+		+	+	+
Fishmeal (imported)	+	++	+		++		++
Blood meal	+		+		+++	++	-
Hydrolyzed feather meal			?		++		-
Carcass & bone meal	+		++		+++		-
Crayfish meal	+		?		?		-
Shrimp waste	?		+		++		-
Chicken layer dropping meal	++						
Fish oil	+		?		+		-
Rendered poultry oil	?		?		+		-
Vitamin and mineral premix*	++	++	++	++	++	++	++

* = Imported; + = limited supply, ++ = readily available, +++ = abundant supply

Source: Bentley and Bentley (2005), Fagbenro and Adebayo (2005), Hasan (2005); Radull, (2005), C. Mudenda, Dept. Fisheries, Zambia (pers. comm.),

country reviews and Hasan (2005), provides a qualitative indication of availability. From the information provided in the country reviews it would appear that the animal feed industry in Kenya in particularly is severely constrained by shortages of suitable ingredients. Table 12 provides an insight into the availability and use of non-conventional ingredients as fish feeds by small-holder non-commercial fish farmers in the region. The proximate composition of the various ingredients (crude protein, lipid, fibre and ash) is provided in the country reviews.

The price of ingredients in the target countries is shown in Table 13. Prices vary significantly between countries and this affects the formulations used by feed manufacturers and farmers. For example, the price of fishmeal ranges from US$1 500 per tonne in Nigeria to US$370 per tonne in Kenya. Both Kenya and Uganda produce substantial quantities of fishmeal from the *Rastrineabola argentea* fishery in Lake Victoria, while the other target countries produce limited quantities of fishmeal (e.g. 9 000 tonnes in Nigeria in 2004). Uganda currently does not permit the import of fishmeal and until recently Nigeria also imposed restrictions on the importation of fishmeal. While some fishmeal is made by small-scale producers in several target

TABLE 12
Non-conventional commodities used by small-scale, non-commercial farmers

Commodity	Cameroon	Ghana	Kenya	Malawi	Nigeria	Uganda	Zambia
Napier & other grasses	Common	Common	Common	Common	Common	Common	Common
Cacao husks	Common	Common	No	No	?	No	No
Cassava leaves	Common	Common	Common	Common	Common	Common	Common
Cassava peels	Common	Common	?	Common	?	?	?
Other vegetable peels	Common	Common	Common	Common	Common	Common	Common
Vegetable leaves	Common	Common	Common	Common	Common	Common	Common
Banana & other fruit leaves	Common	Common	Common	Common	Common	Common	Common
Over ripe fruit	Common	Common	?	Common	?	Common	Common
Dead farm animals	Rarely	Rarely	?	No	?	?	?
Animal viscera	Rarely	?	?	No	Rarely	?	?
Termites	Common	Common	Common	Common	Common	Common	Common
Maggots	Rarely	Rarely	?	Rarely	Rarely	?	?
Rice bran	Common	Common	Common	Common	Common	Common	Common
Wheat bran	If available	?	If available	Rarely	?	If available	If available
Maize bran	Common	Common	Common	Common	Common	Common	Common
Kitchen waste	Common	Common	Common	Common	Common	Common	Common
Trash fish	Rarely	No	Rarely	No	Rarely	Rarely	No

? = No information.

Source: Country reviews

TABLE 13
A comparison of prices (US $ per tonne) of common feed ingredients used in the manufacture of animal and aquafeeds in sub-Saharan Africa

Commodity	Cameroon	Ghana	Kenya	Malawi	Nigeria	Uganda	Zambia
Year	**2005**	**2005**	**2005**	**2006**	**2005/6**	**2005**	**2006**
Fishmeal	1 132	453–1 031	360–990	750	870–1 500	470–670	750
Carcass meal	1 132		450				
Blood meal	1 320				320	420	
Bone meal						190	
Lake shrimp meal			200–400				
Crayfish meal	1 320						
Soya seedcake	679			483		500	694
Sunflower seedcake						160	
Cotton seedcake	301		260	192	305	140	442
Groundnut seedcake	471	544	300		330	170	
Palm kernel oilcake	75	125					
Dry layer droppings	94						
Rice bran	91		90	27			
Maize bran		68	90	30		80	70
Wheat bran	109	68	90				91
Brewery waste	28	2.3	30	150		11	**
Maize	264		191	210–230	345	280	205–240
Millet	283						
Soybean		544		350	460		
Vegetable oils				1 600	1 100		
Fish oil					3 800		
Chicken mash			240	305	800		568
Dairy mash			220				
Pig finisher mash			190		500		470
Mineral mix*/kg						2.8	
Vitamin & mineral premix /kg		8.5	7	6.6		20	

* Made in some countries and consists mainly of cattle horns, freshwater snail shells and oyster shells

** Brewery waste is normally obtained free of charge at the factory gate

Source: Country reviews

countries it is not known what quantities are produced. Given the high price of fishmeal it is fair to conclude that the use of alternative protein sources for fish feed in the region is a priority. The price of oilseed cakes, though readily available, is high and also varies significantly among countries. Soya oil seedcake is the most expensive throughout the region, while cotton oil seedcake is generally available at a lower price.

Moreover, the price of feed commodities also varies seasonally and this also determines the composition of feeds. Many of the smaller commercial farmers in Nigeria (and probably elsewhere) purchase the cheapest feed ingredients on the market irrespective of the nutritional value of the commodity. The majority of small-holder, non-commercial farmers rely largely on enhanced pond productivity (green compost cribs) and supplementary feeding using cereal bran, as and when available. For example, in Kenya over 99 percent of farmers are reliant on this practice.

Trash fish and factory offal is recognised as a possible fish feed in Nigeria, Ghana and Cameroon. However, very little if any, is used as most of it is sold as food for human consumption.

A comparison of prices of some common feed ingredients used in the manufacture of animal and aquafeeds is provided in Table 13.

7. THE ANIMAL FEED INDUSTRY

The animal feed industry in SSA consists of a formal and an informal sector. The formal sector is embedded within the industrial sectors of the countries, while the informal sector consists of small-scale feed manufacturers using less sophisticated machinery and farm-based feed mills that may produce anything from a few kilogram's to several tonnes of feed per day. On the whole the animal feed industry is focused primarily on the production of chicken feed and the formal or commercial feed industry in the group of target countries is best developed in Nigeria.

The total production of animal feeds in the target countries is shown in Table 14. Nigeria, after South Africa (which produced over 4.4 million tonnes in 2005), is the biggest producer of animal feeds in SSA (Shipton and Hecht, 2005). Nigeria produces around 3.8 million tonnes per annum. Kenya with 450 000 tonnes is the third largest producer of animal feeds. Production by the other countries in 2005 ranged from 80 000 to 148 000 tonnes. It should be noted that the data for all countries is not for 2005. The most recent available information for Nigeria for example was for 2000/1. In 2000/1 Fagbenro and Adebayo (2005) estimated that there were some 620 feed manufacturers in Nigeria of which 59 percent were small operators with a capacity of between 0.5 and 5 tonnes/hour. They also calculated that only 51 percent of the production capacity of the formal feed mills was being used. Currently there are 32 industrial scale feed manufacturers in Nigeria (see Table 14 for more details).

TABLE 14
Commercial animal feed* production (tonnes) in target countries

	Cameroon	Ghana	Kenya	Malawi	Nigeria **	Uganda	Zambia
Year	**2004**		**2004/5**	**2005**	**2001**	**2005**	**2001**
Poultry	52 910	>28 000	256 440		2 591 732	68 000	
Pig	15 120		32 630		1 084 214		
Aquafeed	<100		104	620	10 760	√	450
Ornamental fish	√		√			√	√
Unspecified	7 524						
Other			177 081				
Total production	75 594		466 255	>65 000	3 799 925	80 000	>120 000
Production capacity	150 000		?		7 000 000	?	
Number of feed mills: formal and (informal)	8		17 (63)	12 (2)	32 (500+)	27	2 (?)

* Produced by the formal animal feed industry

** Of the 54 large feed mills operating in 2001, only 32 industrial scale feed mills were functional in late 2005. Since early 2006 bird flu has had a serious impact on animal feed production (O. Fagbenro, pers. comm., 2005). The other 500+ feed producers are small-scale private operators and medium scale cooperatives. Over 78 percent of Nigeria's animal feed is made by the informal sector and 81.4 percent of aquafeeds is made by the informal sector. On a total combined basis aquafeed production by the formal and informal sectors only account for about 30 percent of the total estimated annual use. The rest is farm-made

Source: Shipton and Hecht (2005), country reviews and C. Mudenda, Dept. of Fisheries, Zambia (pers. comm.)

8. AQUAFEEDS

Formulated aquafeeds are produced commercially only in Nigeria, Cameroon, Kenya, Zambia, Malawi and Uganda. However, the country reviews reveal that the bulk of the aquafeeds are made on farm or by informal small-scale feed manufacturers (Table 15). In Nigeria it has been estimated that approximately 70 percent of fish feeds are farm-made (Fagbenro and Adebayo 2005). Similarly, while some aquafeeds are made by the formal sector in Cameroon, Ghana, Uganda and Malawi, most of the feeds used are compounded and manufactured on farms and made by small-scale producers. Formal and informal feed manufacturers in all countries have the capacity to make pellets of some sort, although extruded floating pellets are only manufactured in South Africa and Nigeria.

Formulated feeds for *O. niloticus* and/or *C. gariepinus* are manufactured in Cameroon, Nigeria, Kenya and Uganda, and Zambia produces a formulated pellet for *O. niloticus*. No specific feeds for *C. carpio* are compounded. Given the general decline in the popularity and production of common carp throughout the region this is not surprising. Cameroon, Uganda and Kenya also produce small quantities of flake feeds for ornamental fish, which is used by hobbyists. Ornamental fish farmers all use farm-made feeds. Despite better FCR's commercial formulated pellets in most instances are uneconomical to most small-holder fish farmers because of the high unit cost, transport costs and the small-scale nature of their enterprises, hence are used only by medium and large scale operations.

The formulations in most countries vary according to seasonal availability and price of ingredients. The cost of tilapia feeds (20–25 percent crude protein) range from US$225 to 599 per tonne (Table 16).

Both Nigeria and Uganda import feeds for rearing of juvenile clariid catfish from South Africa, the Netherlands and the United States of America. However, it was not possible to obtain sufficiently accurate estimates of imported volumes.

The country reports and the data above suggest that the status of the formal animal feed industry in the target countries ranges from "just established" to "well established". In Nigeria it is comparatively well established, though unregulated, while in Uganda it is in a nascent phase. Fish feeds have only been made since around 1999–2000 in the target countries and the formal aquafeeds industry is currently still in a formative phase and only reasonably well developed in Nigeria and to some extent in Zambia. Except for Nigeria and South Africa, fish feeds in other countries are manufactured by the formal animal feed industry on request. The reports however revealed that the informal aquafeed

TABLE 15
Production of aquafeeds (tonnes) used by the commercial aquaculture sector in target countries

	Year	Formal	Informal and farm-made feeds*
Cameroon	2004	<100 (estimated demand for 2005 = >300 tonnes)	
Ghana	2005	Small pilot scale quantity produced by one company (2 tonnes /month)	547
Kenya	2004		558
Tilapia		59	
Trout		45	
Malawi	2005	620	156
Nigeria	2000/1		
Tilapia		6 554	14 258
Catfish		4 206 (plus 4 000 tonnes of imported feed)	10 552
Uganda	2005	<50 (plus and unknown quantity of catfish starter feed)	3 870
Zambia	2005	450	5 400
South Africa	2004/5	3 864	?

* Except for Nigeria, informal and farm-made feed production in the other countries are calculated estimates, based on commercial production estimates and using a FCR of 1.3 for compounded pellets and 1.8 for farm-made feeds.

Source: Shipton and Hecht (2005), country reviews and www.afma.co.za for South Africa

TABLE 16
Retail price of fish pellets in target countries in US$ per tonne

COUNTRY	Year	Trout	Nile tilapia	African catfish
Cameroon	2006		381–424	943 (starter diet for catfish and tilapia)
Ghana			520	
Kenya	2005	542	225	
Malawi		NA	NA	NA
Nigeria	2005			1 100* to 3 500 for imported catfish starter feed
Uganda	2006		250	300 (35% crude protein, CP) to 6 100 for imported catfish starter feed
Zambia	2006		599	
South Africa**	2006	Pre-starter crumble 48% CP = 2 016 Pre-starter 2mm 48% CP = 1 532 Starter 45% CP = 1 035 Grower 38% CP = 877 Finisher 38% CP = 1 012	Starter 41% CP = 879 Grower 32% CP = 771 Semi-intensive 25% CP = 645	Pre-starter 52% CP = 2016 Starter 41% CP = 879 Grower 35% CP = 715

* = local grow out sinking pellet, ** = Aquanutro (Pty) Ltd. pricelist Feb 2006, NA=Not Applicable

Source: country reviews

sector, consisting of small-scale feed manufacturers as well as on-farm facilities, provides the bulk (60 percent and above) of the requirements of commercial farms. This situation is simply a reflection of economies of scale. The demand for formulated aquafeeds in the target countries (except Nigeria) is relatively small and hence it is not economically viable for the formal sector to invest in dedicated aquafeed lines. The presently available information for Cameroon, Nigeria and Zambia suggests that only between 50 and 65 percent of the formal industry's total capacity is being utilized, which means that the industry could and probably would be able to provide for the needs of the industry if and when the demand reaches critical mass. For example, within the South African economic realm a feed mill would only invest in a dedicated feed line and associated costs (quality control, personnel etc) if the demand for a specific feed exceeds 5 000 tonnes per annum (L. de Wet, Aquanutro (Pty) Ltd, 2006, pers. comm.).

It is clear from the country reports that the formal aquafeed industry, in general, is still in a developing phase. In Nigeria the aquafeed industry only emerged in 1999/2000 as a consequence of the upsurge of African catfish production and the resulting demand for feed. In all countries were aquafeeds are produced there are problems with consistency of supply and quality. The percentage of fines may be as high as 50 percent (personal observation). In the absence of information on capacity within the industry it is probably correct to assume, given the low demand for aquafeeds, that manufacturers do not pay much attention to aquafeed quality control. It is perhaps for this reason that farmers in Nigeria, and elsewhere, still prefer to deal with small-scale feed producers, with whom they have established a feedback system with respect to fish performance and food conversion ratios. For example, in Nigeria 69.75 percent of the 35 570 tonnes of fish feed produced in 2001 was "farm-made" feed. Catfish farmers in Nigeria and Uganda now also import a starter diet for African catfish from South Africa, the Netherlands and the United States of America. Nigeria imported just over 4 000 tonnes of catfish feed in 2004. It would appear that rapid steps, inclusive of foreign investment, are being taken in Nigeria to supply the 27 000 tonne demand for catfish feeds.

9. FARM-MADE FEED FORMULATIONS AND MANUFACTURING TECHNOLOGY

The emergence of informal small-scale fish feed manufacturers in most target countries is extremely encouraging and suggests that commercial aquaculture in the region is expanding. Several farm-made feed formulations as used in the region are shown in

Table 17. It was not possible to obtain specific feed formulations from the formal sector. Three basic feeds are manufactured, namely a starter diet for African catfish and tilapia with a protein content of between 40 and 45 percent, grower formulations for tilapia (also used for carp and other species) with a protein content ranging from 20 to 28 percent and a grower formulation for African catfish with 32–40 percent CP. Several of the formulations are based on research undertaken at local universities or research institutes or have been formulated by farmers based on the nutritional requirements of the dominant species.

TABLE 17
Some typical formulations (percent), proximate composition and price of feeds made by small-scale feed producers and/or manufactured on-farm

Diet	1	2	3	4	5	6	7	8	9	10	11	12	13
Ingredient composition													
Fishmeal		20	55		50	25	15	16		30	2	11	30
Blood meal						10					48	13.5	5
Carcass meal													15
Bone meal	1		4										
Lake shrimp meal									34				
Soya meal						35	45						15
Soya oilcake	13	15	5									3	
Cotton oilcake	15	15	5		9						2	4	
Groundnut oilcake	12	5	4					17					
Sunflower oilcake				30									
Copra cake								17					
Brewery waste	10	15	10										
Rice or wheat bran	20	15	2						66			8	
Wheat bran					25			50					22
Maize bran				50						70	48	7	10.5
Cocoa husk / Coffee pulp	10												
Layer dropping meal	15												
Maize		8	3			15	25					49	
Maize germ					15								
Pigeon pea meal				20									
Cassava flour												4	
Palm oil	2	2	5										
Vegetable oil						4	6						
Fish oil						6	4						
Starch/binder						2	2						
Vitamin & mineral premix	2	5	5		1	3	3					0.5	2.5
Proximate analysis													
Crude protein (%)	28.5	34.5	43.3	20		40	38	25					37
Crude lipid (%)	8	9	11				9	5					9.4
Energy (kJ/g)	?	19.2	20.4										
Cost per tonne (US$)	381		943	148			547	227	153	176	270	425	600
Retail price (US$/ tonnes)												519	

1 = Grower formulation (CP 31%) for *O. niloticus* farming in fertilised ponds (Cameroon).
2 = Grower formulation for intensive *O. niloticus* farming (Cameroon).
3 = Starter formulation (CP 45%) for *C. gariepinus* and *O. niloticus* (Cameroon).
4 = Grower formulation for *C.carpio* and *O. mossambicus* in fertilised ponds (Malawi).
5 = Grower pellet for *C. gariepinus* (Kenya).
6 = Grower pellet for *C. gariepinus* (Nigeria).
7 = Grower pellet for *O. niloticus* (Nigeria).
8 = Tilapia grower pellets (Kenya).
9 = Grower pellet for *C. gariepinus* (Kenya).
10 = Farm-made grower formulation 1 (Uganda).
11 = Farmer made *C. gariepinus* grower formulation (Uganda)
12 = Industrial pellet formulation for *O. niloticus* and *C. gariepinus* polyculture (Cameroon)
13 = Catfish, carp and tilapia fingerling and broodstock formulation (Malawi)

Source: country reviews

Several different kinds of farm-made feeds are produced, ranging from formulated mixes fed to the fish in punctured bags (adapted from India) as practised in Malawi, to moist feed cakes and dry pellets. Preparation and manufacturing technologies are simple. The raw materials are milled and mixed at pre-determined ratios. Ingredients are mixed by hand or mechanical devices such as cement mixers. Some of the ingredients such as soybean meal and maize meal are precooked (to eliminate anti-nutritional factors where these exist, to improve digestibility and to improve binding capacity). Warm or hot water is added to the final mixture to make a firm dough. Pellets are hand made by extruding the dough through a meat-mincer or pasta maker (hand or electrically operated). The "spaghetti's" are then sun dried or dried in locally manufactured driers and cut or crumbled into appropriate sizes. In some instances farmers order their preferred formulation in milled form and extrude their own pellets on-farm. Figures 14 to 17 illustrate some of the on-farm feed manufacturing technologies and products.

There are several common problems in the production of farm-made feeds. Many small-scale manufacturers throughout the region do not use an anti-oxidant, except in Nigeria were producers add Sodium propionate at an inclusion level of 0.1 percent as an anti-mould agent. Storage time is therefore reduced and the incidence of spoilage is high. However, the main problem associated with pellets produced by small-scale producers, is the high percentage of fines resulting in a high degree of wastage and poor FCRs. Catfish farmers in Nigeria report FCRs between 2 and 3:1 and above in comparison to 0.95 using imported floating pellets. However, the cost of the

FIGURE 14
Cooking feed ingredients in Malawi (left) and locally made feed in mixer in Kenya (right)

COURTESY OF M. UOMIZO AND M. MBUGUA

FIGURE 15
On farm pelleting in Nigeria (left) and pellet plunger and handful of dried pellets (right)

COURTESY OF O.A. AYINLA

FIGURE 16
Sun drying fish pellets (left) and (right) wind tunnel feed dryer

COURTESY OF V. POUOMOGNE AND R. BRUMMETT

FIGURE 17
Home made aquarium fish flakes in Cameroon (left) and (right) farm-made pellets in Nigeria

COURTESY OF T. MBONGO AND OF O.A. AYINLA

TABLE 18
Maximum recommended inclusion rates of unconventional feed ingredients

Ingredient	Maximum inclusion rate (%)	Replacement	Species
Groundnut cake	25		
Palm kernel cake	10–15		
Cottonseed cake	20–30		
Jackbean	10–30	Soybean meal	*C. gariepinus*
Winged bean	50	Fishmeal	*C. gariepinus*
Poultry offal	10		
Sorghum	50		
Cassava	40		
Sweet potato	20		
Fish silage	40	Fishmeal	*C. gariepinus*
Shrimp head meal	10	Fishmeal	*C. gariepinus*
Macadamia presscake	50	Protein source	*O. niloticus*
Poultry by-product silage	15–30	Protein source	*C. gariepinus*
Duckweed	15	Any carbohydrate source	*Tilapia*
Corn oil	10		
Soybean	10		
Palm oil	10		
Periwinkle shell	7.5		
Limestone	5		
Malt dust	2		
Coffee bean pulp	20		
Cacao husk	20		

Source: see Ayinla (2007) and Pouomogne (2007) for detail and data sources

imported floating pellets for grow-out is uneconomical and farmers now only use the imported starter pellets for a short period before switching to farm-made feeds.

Moreover, small-scale feed producers and commercial fish farms most often do not have adequately sized and pest proof storage facility. This prohibits bulk purchase of raw material when prices are low.

The price of farm-made feeds is generally lower than the products from the formal sector (e.g. US$154 to 750 per tonne for farm-made feeds vs. US$227 to 1 110 per tonne for industrially made pellets (excluding imported pellets) (see Tables 16 and 17). Depending on feeding practices FCRs of 1.1:1 have been reported for some farm-made feeds in Uganda and Kenya. Moreover, as mentioned above, farmers who make their own feeds are normally also in a position to purchase raw materials directly from producers, so that the middleman is cut out, which results in significant savings. The reported average FCR for farm-made feeds is around 2:1 (range 0.95 to 3.8:1), although upper level estimates by the author are in the region of 8:1.

There has been an intense research focus on the use of alternative ingredients and agricultural by-products to replace fishmeal in fish feeds, optimal inclusion rates and feed formulation, particularly in Nigeria, and to some extent in Cameroon and Malawi (see country reports). Moreover, there is an excellent body of knowledge with respect to the proximate composition of most non-conventional ingredients that may be used in fish feeds (see country reports). Table 18 summarizes the recommended maximum inclusion rates for some of these ingredients. For many years this research was considered to have little impact on the development of commercial aquaculture in the region. However, with a growing need for fish and a rapidly developing commercial aquaculture sector this has changed and many non-conventional ingredients, depending on price, are now used by small and medium scale informal feed producers.

10. FEEDING PRACTICES

Feeding practices are as diverse as the feeds used in the region. The most commonly used feed by non-commercial farmers is maize or rice bran, which is spread over the water surface. This practise is wasteful as any breeze will blow the feed into the grassy verges of the ponds, where it is unavailable. Some farmers have realised this and use floating rings made of grass that are attached to a stake. The bran is placed into the rings to contain it and to ensure that feeding is optimised. Some farmers also place grass ropes over the water surface area in a square pattern and depending on wind direction will place the feed (bran or vegetable leaves) into a pre-selected square (Figure 18). Vegetable matter (where reported in the country reviews) is generally not chopped prior to feeding.

FIGURE 18
Floating grass pond divisions for improved feeding with leaves or bran

Though farmers are aware of the importance of feeding their fish (Hecht, 2006), it would appear that non-commercial farmers feed their fish less than once a day and with an inadequate ration and many rely entirely on natural pond productivity. To a great extent this is a consequence of the financial circumstances of the farmer.

In all instances fish on commercial farms are fed regularly at fixed rations and schedules that are adjusted according to average fish weight. Feeding frequencies range from 2 times per day in earthen ponds to 6 times per day for juvenile African catfish under high density tank culture conditions, to 1 or 2 times daily during grow-out. Feeding is done mainly by hand, except for some experimental trials using automatic feeders or demand feeders in high density catfish culture in tanks (Nigeria) and tilapia cage culture (Ghana and Malawi).

Most farmers feed dry pellets or a formulated mash to juvenile tilapia. However, several farmers use formulated wet dough, in some instances bound with sugar cane molasses. The dough is offered to the juvenile fish in baseball size portions on submerged feeding trays. According to one of these farmers this method allows for better visual inspection and observation of feeding intensity and fish health and reduces feed wastage (S. Pala, Aquafarms, Malawi, pers. comm.). The feed balls are made every second day.

11. PROBLEMS AND CONSTRAINTS

Some of the problems and constraints facing feed manufacturers in general and the farmers in particular have already been mentioned briefly in the preceding sections. The following bullets summarize the general constraints as expressed in the country reviews:

- variable ingredient quality and proximate composition;
- general shortage of fishmeal and within country variability in supply;
- inter-annual variability in supply of raw materials;
- competition for raw materials for human nutrition (e.g. *Rastrineobola argentea* fishmeal in Uganda and Kenya) and the chicken feed industry (e.g. maize, brans, fishmeal, oilseed cake);
- farmers in rural areas have poor access to feeds and fertilizers (cost of transport increases price beyond their means);
- small scale feed manufacturers are limited by their ability to store raw materials (pest control and warehouse space);
- poor and careless packaging of manufactured feeds;
- seasonal fluctuations in commodity prices (related to agricultural calendar);
- high level of fines in dry pellets;
- poor feed conversion ratios of some farm-made feeds (>4:1);
- high rate of spoilage of raw materials and feeds (mould, insects and rodent faeces);

- high transport costs (US$0.35 to US$1.00 per km for small loads less than 1 tonne) (e.g. transport adds minimum of 25–30 percent to cost of all imported goods in landlocked countries);
- high duty on imported feeds and raw materials;
- lengthy customs clearance of raw material;
- lack of affordable industrially manufactured feeds;
- poor quality of industrially manufactured feeds and lack of quality control;
- lack of adequate feed manufacturing equipment (symptom of low demand and investor hesitancy);
- limited and inadequate funding for research;
- operating within poor governance structures; and
- lack of expertise in feed manufacturing technologies.

While several of the constraints are uncontrollable factors (e.g. inter annual variability in supply and price of raw materials) many of them are typical of poor quality control in an unregulated industry, where the end user is to a large extent at the mercy of the supplier. The upswing in the number of small-scale feed producers in Nigeria and Cameroon is therefore not entirely surprising since it allows for better quality control and feedback. In most countries, except perhaps in Nigeria, the commercial aquaculture sector will for the foreseeable future be dependent on small-scale feed producers and farm-made feeds. The situation will only change if and when there is a critical mass of demand for high quality industrially manufactured feeds such that industry would risk the initially high investment costs. The situation however provides competitive advantages to small-scale operators to gear up and grow with the aquaculture sector. Given the growth of the aquaculture sector in many SSA countries governments must be sensitised as to the potential of aquaculture and the need for incentives to stimulate the aquafeed industry and of the need for quality control measures. Moreover, the high cost of imported feeds may in fact be inhibiting the growth and development of the catfish farming sector.

Many of the constraints listed above are issues related to economies of scale. For example, small-scale feed producers will only invest in improved and larger storage facility if and when the demand for feed exceeds a certain threshold. Governments in all countries should and must play a more facilitating role, such as reducing or abolishing import duty on raw materials and improving the efficiency of customs and excise for speedy release of perishable goods. Policy on these issues is being revised in Cameroon, Nigeria, Malawi, Kenya and Uganda.

There is no doubt that there is lack of capacity in feed technology throughout the region. Many, if not most, donor funded projects in the past have focused on fish nutrition in some or other way. However, to our knowledge there has not been one project that has focused specifically on feed technology. There is a serious need to address this shortcoming by the provision of training opportunities and most importantly by the inclusion of feed technologists in donor funded aquaculture development programmes. In essence, aquaculture in SSA has now developed to stage where it is no longer appropriate for donor countries to send general aquaculture practitioners to partner countries. The time has arrived for deploying specialists to foster the growth of the sector.

12. LABOUR COST

Labour requirements are dictated by the size of the farm, intensity of production and the level of management employed. The average daily wage in the target countries is US$1.10 per day (Range US$0.75 to US$2.70). From the data presented in Table 19 it can be concluded that the cost of labour in all countries is low in comparison to the rest of the world. It was unfortunately not possible to calculate a realistic figure for labour cost as a proportion of total production cost per tonne of fish produced.

However, as mentioned elsewhere the cost of labour, despite the low daily wage structure, is prohibitive to most small-holder farmers and restricts their on-farm activities.

TABLE 19
Labour requirements

Farm size/number of ponds (Max. pond surface area)	Scale of intensity	Labour units required
1–4 ponds (0.1ha)	Extensive	1
1–2 ponds (0.2ha)	Semi-intensive	2
3–10 ponds (1ha)	Semi-intensive	4–8
Tank or raceway (25 tonnes/year)	Intensive	8
Tank or raceway (50 tonnes/year)	Intensive	12

Source: Country reviews and interviews with farmers

13. COMMENTS ON RESOURCE AVAILABILITY AND EXPANSION OF THE AQUACULTURE INDUSTRY

In a reassessment of Kapetsky's (1994) strategic assessment of warm water fish farming in Africa, Aguilar Manjarrez and Nath (1998) showed that 50–76 percent of Africa's land, despite several constraints, has the highest pond culture yield range potential for Nile tilapia, African catfish and common carp. Because of environmental tolerances the spatial distribution of carp culture potential was found to be greater than for Nile tilapia and African catfish. However, carp culture throughout the region is declining, probably as a consequence of consumer preference and higher returns with the other two species. All countries, except Malawi, Uganda and Zambia were shown to have adequate resources for the expansion of pond based aquaculture. The potential in Zambia is theoretically constrained by the high proportion of land incorporated as protected areas (>30 percent of surface area), while the potential for pond aquaculture in Malawi and Uganda is constrained by lacustrine environments and in the case of Malawi the high population density in the most suitable areas. The potential of cage culture was however not explored by Aguilar Manjarrez and Nath (1998). Given the success of Nile tilapia cage culture in Lake Kariba highlights the opportunities presented by the African Great Lakes in Uganda, Kenya, Zambia and Malawi, as well as in other lakes and large man-made impoundments. Aguilar Manjarrez and Nath (op cit.) also considered urban areas as a constraint for aquaculture development. However, the notion that urban areas constrain aquaculture development has recently been challenged by Costa-Pierce *et al.* (2005) and indeed urban and peri-urban aquaculture is perhaps the most rapidly expanding sector in Cameroon, Ghana, Nigeria and Uganda (Rana *et al.*, 2005). Moreover, Aguilar Manjarrez and Nath (1998) suggest that all the countries considered in this review (see country reviews for details) have the required environmental conditions, livestock waste and agricultural by-products for the expansion of the sector. Aguilar Manjarrez and Nath's (1998) general conclusions are discussed below in relation to current observations and the projected expansion of the sector.

It is clear from the country reviews that there are sufficient gross quantities of animal manure in each of the target countries to satisfy the needs of aquaculture. However, as mentioned previously, an increase in production by small-scale farmers will continue to be constrained in most instances by the small number of farm animals and the cost of transporting manure from source to farm. The problem of manure availability facing small-holder fish farmers cannot and should not be considered on a country basis. The problem can only be addressed at the district level, where the requirements can be realistically quantified by the responsible lead agency or by NGOs and for them to then devise the most appropriate and cost effective manner of delivering manure to communities in conjunction with farmers.

The commercial sector in all target countries appears to be split, in various proportions, between stand alone fish farms and those in which aquaculture is integrated with other animal husbandry or agricultural activities, e.g. cattle, chicken, pig or grain farming. Under such conditions the availability of manure is obviously not a problem. However, commercial stand-alone pond fish farms of whatever scale that have to source manure from chicken producers or cattle farms may face competition from other users of manure. However, the current average price of chicken and cattle manure is low particularly in Malawi, Nigeria, Uganda and Zambia, suggesting that access to the resource should not be problematic in the short to medium term.

Inorganic fertilizers are rarely used to enhance pond productivity in the target countries. This may be related to the high price and the general scarcity of fertilizers in all countries.

During the last five years (see Table 3) aquaculture production has increased significantly in most target countries and as mentioned previously approximately 70 percent is produced by the commercial sector. Because the vast majority of "non-commercial" fish farmers use farm by-products and / or rely on natural pond productivity for fish production, the projected future requirements for fish feeds has been calculated for the commercial sector only. The projections are illustrated in Table 20 and are discussed on a per country basis below. The estimation procedures did not consider the impacts of future commodity prices (particularly fishmeal and oil seed cakes) as well as factors that could have a negatively impact on production cost (e.g. international oil prices, inflation and cost of electricity) on the demand for feeds.

According to FAO statistics the aquaculture sector in Cameroon over the last five years has grown by over 112 percent per annum. Clearly, the sector is making rapid advances and examples set by some commercial farmers are being copied in increasing numbers by others, particularly in peri-urban areas. The manufacture of aquafeeds is a recent initiative in Cameroon and only 80–90 tonnes were produced in 2005. The current animal feed production capacity is around 150 000 tonnes and only 50 percent of this capacity is presently utilized. At the moment most commercial farmers use farm-made feeds. Agricultural products and by-products used for the manufacture of animal feeds, except fishmeal, are readily available and the formal feed industry has the capacity to provide feeds under any one of the three growth scenarios.

In Ghana the sector has not shown the same high growth rate as in Cameroon. Commercial aquaculture has only emerged during the last five years but is already contributing between 30 and 35 percent of total production. Only small quantities of fish feeds are made on a pilot scale level. (ca. 2 tonnes per month). The country has a seemingly well established animal feed industry (though no quantitative data were provided). Fishmeal is mainly imported. The report by Abban (2005) suggests that Ghana has adequate oilseed cake resources to supply and future demand by aquaculture. As in other countries most commercial farmers at this stage use farm-made feeds and their feed production capacity exceeds their requirements.

In 2005, Kenya produced just over 100 tonnes of compounded fish feed for trout and tilapia. The country's feed industry is, within the group of countries examined, the second largest after Nigeria, producing over 450 000 tonnes. The animal feed industry in Kenya is relatively new, having been developed during the past 10 years. As elsewhere, most commercial farmers use farm-made feeds or feeds produced by small-scale feed producers. Kenya has adequate agricultural by-product resources though the competition for locally produced fishmeal is intense, as it is also used for human consumption and other animal feeds. Fishmeal supply, currently standing at around 30 000 tonnes per annum, is considered to be the major constraint facing the animal feed industry as a whole. Even if aquaculture grows from its current base at 15 percent per annum until 2020 the industry would require just under 2 percent of the current animal feed production capacity. The Association of Kenya Feed Manufacturers was formed in 2003 and functions as the industry's voice to government.

After many false starts, commercial aquaculture in Malawi emerged in 2003. The largest cage culture operation in the SSA region is currently being developed in Lake Malawi, using indigenous tilapia, *O. karongae* and *O.shiranus* The company will probably reach its production target of 3 000 tonnes in 3–5 years. At a conservative FCR of 1.5:1 this single operation (excluding the requirements for broodstock maintenance and fingerling production) will require some 4 500 tonnes of feed per annum. If this venture is successful then others will most certainly follow, which will increase the demand for pelleted feeds substantially. The farm has installed a feed mill and pelletizer but will probably not be able to, or want to, manufacture its own feeds at full production. The Malawian scenario is different from that in other countries in that the establishment of a single operation within a short time will create a demand for a substantial quantity of formulated pellets. Though there are about 12 animal feed producers the animal feed industry in Malawi is small, though fairly well established. As elsewhere it is heavily reliant on imports (maize, oilseed cake and all fishmeal) and as in the other target countries produces mainly poultry feed. In 2005 the industry produced approximately 600 tonnes of formulated milled product for fish pellets. Amongst other variables, the success of the cage culture operation in Malawi therefore also hinges on co-operation with the formal feed industry. There is no animal feed association in Malawi and all companies operate independently of each other, however the Malawi Bureau of Standards regulates feed quality in the country. A call has recently been made to improve the regulatory environment of the animal feed industry in Malawi.

Nigeria has shown the most dramatic increase in fish production, from 30 677 tonnes in 2003 to 43 950 tonnes in 2004, mainly as a result of significant increases in African catfish and Nile tilapia production. Nigeria has the largest animal feed industry in SSA after South Africa, producing around 4 million tonnes per annum. Currently there are 32 functional commercial scale animal feed mills (O. Fagbenro, pers. comm. 2006). Over 35 000 tonnes of aquafeed was produced in 2003, of which approximately 60–80 percent was farm-made or produced by small-scale feed producers. Oilseed cake and other primary agricultural products and by-products for animal feeds in Nigeria are in short supply and the country is reliant on imports of oilseed cake, soybean and fishmeal. An adequate supply of fishmeal is recognised as the major current and future constraint, unless the country's unexploited lanternfish resources are utilized. Only 13 percent of its annual fishmeal consumption was produced locally in 2004, while the bulk of the 2004 demand (67 500 tonnes) was imported. All feed additives in Nigeria (as well as in other countries) are imported. However, Nigeria has the capacity and expertise to produce the required quantity of feed under any of the projected growth scenarios. Several foreign companies are currently investing in aquafeed mills. Nigeria and Uganda are currently the only countries that import fish feeds, mainly from South Africa and specifically for early juvenile rearing of African catfish under intensive farming conditions. There is no animal feed manufacturing association in Nigeria and the industry is unregulated and not controlled by any organ of state with respect to quality and bio-safety. Given that the animal feed industry is only operating at 56 percent efficiency (Fagbenro and Adebayo 2005) it is well placed to provide the needs of the aquaculture sector in future, though its participation in meeting the aquafeed requirements, as in other countries, depends entirely on the quality of the product it can produce.

Aquaculture in Uganda is growing at a rapid rate. The animal feed industry in Uganda was started around 1994 and currently produces around 80 000 tonnes. The country is well endowed with natural resources and except for soybean produces adequate quantities of produce and by-products that are readily available to the feed industry. It has a reduction fishery of some 50 000 tonnes and fishmeal is also made from the offal of the Nile perch fishery in Lake Victoria. However, because no fishmeal is imported the competition for this commodity is intense and has serious negative social implications in that the fish previously used for human consumption is now used mainly for fishmeal. Aquafeed production is sporadic and is only produced on request and the quality is poor. Most commercial farmers make their own feeds or purchase it from informal feed producers. Uganda has developed a policy for animal feeds as well as a draft bill to safeguard consumers and to ensure feed quality.

Total fish production in Zambia is around 5 000 tonnes of which around 75 percent is produced by the commercial sector. The animal feed industry is well established and produces over 120 000 tonnes per annum. In 2005 some 450 tonnes of fish feed was produced and until 2004 an unknown quantity of fish feed was imported from Zimbabwe. Most of the commercial farmers produce their own feeds. Agricultural by-products and other feed ingredients are readily available in Zambia though fishmeal is scarce and is imported, mainly from Namibia. The formal feed sector has the capacity to increase fish feed production

A common denominator throughout the region is that many, if not most, commercial farmers rely more on farm-made feeds and feeds produced by the informal sector than on the formal animal feed sector. This scenario will probably continue until such time as the demand in the various countries reaches a critical mass. All countries have established animal feed industries, which are capable of accommodating the demand of the commercial aquaculture sector. However, at this stage the common complaint is poor feed quality, particularly with respect to the high percent of fines, water stability and poor FCRs. Unless there is a certain minimum demand it is highly unlikely that the formal feed industry, with its focus on poultry feeds, would gear up in any of the countries to manufacture high quality, competitively priced fish feeds. Hence the small-scale aquafeed producers have a competitive advantage. The synergistic growth of the commercial aquaculture and small-scale feed producing sectors should therefore be strongly encouraged and supported. The projected demand for aquafeed under three different growth scenarios of 5, 10 and 15 percent per annum (Table 20) is substantial and certainly provides opportunity for some of the current cadre of small-scale feed producers to carve a profitable niche for themselves. Overall, commodities for inclusion into fish feeds in the target countries are readily available, though seasonal price fluctuations can be significant. This has a serious impact on small-scale producers who generally do not have adequate storage facility to purchase product when prices are low (usually immediately after harvest). Fishmeal throughout the region is a constraint, with respect to quality and quantity and most countries are largely dependent on imports.

14. RECOMMENDATIONS

Recommendations for improved utilization of fertilizer and feed resources including suggested policy guidelines emanating from the country reports can be grouped into four major categories, viz. (i) Technological; (ii) Research and Development; (iii) Outreach; (iv) Policy and legal.

i) Technology

The country reviews reveal that there is a serious lack of capacity and knowledge with respect to feed technology. It is therefore necessary to;

- train private and public sector nutritionists and fish feed technologists (formulation, pelleting, on-farm feed formulation and manufacture, small-scale feed manufacturing);
- design, adapt and develop appropriate low-cost machinery for milling, mixing and feed manufacture;
- adapt and improve low cost feed drying technologies; and
- design, develop and test appropriate bulk storage facilities to prevent spoilage as a mitigating measure against seasonal price fluctuations.

ii) Research and development

It is necessary to:

- evaluate alternate feed ingredients and determine optimum inclusion rates;
- quantify the demand for animal manure in aquaculture at district level and devise low-cost distribution plans;

TABLE 20
Projections of aquaculture production and aquafeed requirements in target countries for 2010 and 2015*

Periods	Cameroon			Ghana			Kenya			Malawi			Nigeria			Uganda			Zambia		
2003/04/05		2005			2004			2004			2005			2004			2003			2003	
Aquaculture production (tonnes)		820			950			1035			800			43 950			5500			4490	
Contribution of commercial aquaculture (%)		8			30			41			12			80			40			75	
Aquafeed production (tonnes)		90			<50			104			720			>35 570			<50			>750	
Growth rate (% per annum)	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15
2010																					
Projected aquaculture production (tonnes)	1 046	1 320	1 649	1 212	1 529	1 687	1 320	1 666	2 081	1 021	1 288	1 609	56 092	70 781	88 399	6 752	8 857	11 062	5 730	7 231	9 030
Projected contribution of commercial aquaculture (%)	15	15	15	35	35	35	45	45	45	55	55	55	80	80	80	40	40	40	75	75	75
Projected commercial aquaculture (tonnes)	156	198	247	424	535	590	594	749	936	561	708	884	44 873	56 624	70 719	2 700	3 542	4 424	4 297	5 423	6 772
Aquafeed demand (tonnes)	234	297	371	636	802	885	891	1 124	1 404	842	1 062	1 327	67 310	84 937	106 078	4 051	5 314	6 637	6 446	8 134	10 158
2015																					
Projected aquaculture production (tonnes)	1 335	2 126	3 317	1 547	2 464	3 395	1 685	2 684	4 187	1 303	2 074	3 236	71 589	113 994	177 802	8 617	14 265	22 250	7 313	11 645	18 164
Projected contribution of commercial aquaculture (%)	30	30	30	45	45	45	55	55	55	65	65	65	80	80	80	55	55	55	75	75	75
Projected commercial aquaculture (tonnes)	400	637	995	696	1 108	1 527	926	1 476	2 302	846	1 348	2 103	57 271	91 195	142 241	4 739	7 845	12 237	5 484	87 337	13 623
Aquafeed demand (tonnes)	600	955	1 492	1 044	1 663	2 291	1 390	2 214	3 454	1 270	2 022	3 155	85 906	136 793	213 361	7 109	11 768	18 356	8 227	13 100	20 434
2020																					
Projected aquaculture production (tonnes)	1 704	3 428	6 672	1 974	3 968	6 828	2 151	4 323	8 421	1 663	3 341	6 509	91 368	183 590	357 623	10 998	22 974	44 753	9 334	18 755	36 535
Projected contribution of commercial aquaculture (%)	60	60	60	60	60	60	70	70	70	70	70	70	80	80	80	70	70	70	75	75	75
Projected commercial aquaculture (tonnes)	1 022	2 056	4 003	1 184	2 380	4 096	1 505	3 026	5 894	1 164	2 338	4 556	73 094	146 872	286 098	7 698	16 081	31 274	7 000	14 066	27 401
Aquafeed demand (tonnes)	1 533	3 084	6 004	1 776	3 571	6 145	2 258	4 539	8 842	1 746	3 508	6 834	109 641	220 308	429 147	11 547	24 122	46 990	10500	21 099	41 101

*Data and assumptions: Baseline fish production data obtained from country reviews, except for Uganda and Zambia for which the FAO Fishstat estimates for 2003 were used. Estimates of current commercial production as a percent of total production obtained from Hecht (2006). Increase in commercial aquaculture contributions estimated from percent increases in total production over last 5 years. Estimates of aquafeed requirements calculated on basis of commercial production at an FCR of 1.5, which is below the current average FCR of 2.0 obtained by commercial fish farmers in the region. The projections are based on three growth scenario's of 5, 10 and 15 % per annum.

Source: Shipton and Hecht (2005), FAO (2006) and author's calculations

- develop appropriate agro-ecological fertilization regimens;
- undertake surveys and develop databases of available feed resources at district or provincial basis;
- develop and test country specific "farm-made" feed formulations;
- develop and test appropriate feeding table; and
- develop and test appropriate feeding methods to reduce waste and improve FCR.

iii) Outreach

For maximum impact the outreach listed below should focus specifically on districts or regions with high aquaculture potential; mainly to:

- train farmers, NGOs and extension staff in food storage methods;
- disseminate information on availability of ingredients suitable for fish feeds;
- disseminate information on "farm-made" feed formulations to fish farmer associations, farmers, NGOs and extension staff;
- disseminate information on manufacturing technology for "farm-made" feeds to fish farmer associations, farmers, NGOs and extension staff;
- disseminate information on feeding schedules and improved feeding practices to fish farmer associations, farmers, NGOs and extension staff; and
- provide support services to small-scale feed producers to fine tune their production processes and technologies to achieve optimum results.

iv) Policy and legal

It would appear from the country reviews that the animal feed industry in most countries is inadequately regulated. Hence the relevant legislation, where this exists, should be reviewed and amended to support the development of the industry. Cameroon and Kenya are in the process of reviewing their legislation with respect to the feed industry. The most pertinent recommendations are listed below:

- governments and financial institutions must be sensitized with respect to business opportunities offered by the aquaculture sector;
- governments in all countries should provide incentives for the development of the animal feed industry (including aquafeeds);
- the feed industry must be encouraged and assisted in lobbying governments to change the legislation on import duty of raw materials and feeds (e.g. Ugandan farmers have to pay holding tax at 6 percent, value added tax at 18 percent and import duty at 10 percent for catfish feed from South Africa). and
- governments must be made aware of the need to regulate the formal and informal animal feed industry, particularly in terms of quality assurance and certification.

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COUNTRY REVIEWS AND CASE STUDY: ASIA

Analysis of feeds and fertilizers for sustainable aquaculture development in Bangladesh

Benoy K. Barman and Manjurul Karim
WorldFish Center, Bangladesh and South Asia Office
House 22B, Road 7, Block F, Banani, Dhaka 1213
Bangladesh

Barman, B.K. and Karim, M. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Bangladesh. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 113–140.

SUMMARY

This study focuses on feeds and nutrients used under different aquaculture farming systems and practices in Bangladesh, which include:

- extensive and semi-intensive systems for the production of carp species (Indian and Chinese major carps, common carp, Java barb) and to a lesser extent tilapia and catfish. Over 89 percent of aquaculture production in Bangladesh is derived from these systems. An overview of feed and nutrient utilisation in these systems as well as their diversity, complexity and production potential are presented;
- intensive culture systems for sutchi catfish (*Pangasius hypophthalmus*) (local name: Thai pangas). These have typically developed in clusters in several regions and depend largely on the use of farm-made feeds, pelleted feeds supplied either by the industrial aquafeed industry or by small-scale aquafeed mills. The increase in the number of small-scale feed manufacturers is a direct response to the growth in demand for pelleted feeds; and
- systems for the production of black tiger shrimp and giant freshwater prawn. These include hatcheries, nurseries and grow-out facilities. Black tiger shrimp (*Penaeus monodon*) and giant freshwater prawn (*Macrobrachium rosenberergii*) production is expanding rapidly and now contributes to the export earning of Bangladesh. Developments in feed manufacturing technology and improved fertilization are critically important for the expansion of the industry. The use of feeds and nutrients in crustacean culture has been analysed based on existing farming practices.

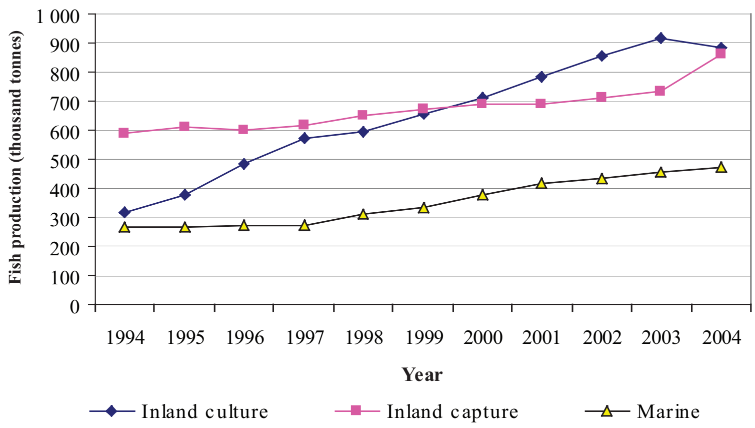
The increase in aquaculture production in many Asian countries is mainly a consequence of the expansion of semi-intensive, small-scale farming systems and the more appropriate use of feeds and nutrients (Hasan, 2001). In Bangladesh, the average yield from fishponds has increased from 0.85 tonnes/ha/year in 1986 to 2.48 tonnes/ha in 2005. Potential exists to further increase production through improved use of feeds and fertilizers. Even minor increases in production levels in the extensive and semi-intensive farming systems would make significant contributions to total fish production in Bangladesh. To achieve this goal there is a need for a better understanding of the production systems, the quality, quantity and frequency of feed and fertilizer application and the use of different species.

Different types of fertilizers and feeds (single ingredient or compounded) are used in the diverse array of systems. The formal and informal aquafeed industries in Bangladesh are developing rapidly, collectively contribute to job creation and improved aquaculture production. This study analyses the potential for development and the constraints facing the aquaculture sector in Bangladesh, with particular reference to feeds and fertilizers. Recommendations are made to facilitate the sustainable development of the sector in the country.

1. INTRODUCTION

The fisheries sector in Bangladesh plays a vital role in the supply of animal protein, creating employment, earning foreign currency and alleviating poverty. The contribution of the sector accounts for 4.92 percent of GDP, 5.7 percent of total export earnings and directly and indirectly employs approximately 12 million people (BBS, 2004). During the period 1995–96 to 2004–05 fish production in Bangladesh increased by 75.3 percent from 1.264 million tonnes to 2.216 million tonnes and the contribution by aquaculture to total domestic fish supply increased from 31 to 40 percent (Figure 1). Similarly, export volumes and earnings of fish and fish-products increased from 39 391 tonnes (US$263 million) in 1999–2000 to 63 377 tonnes (US$373 million in 2004–05 (DoF, 2006). Export earnings are largely contributed by black tiger shrimp, *Penaeus monodon* and giant freshwater prawn, *Macrobrachium rosenbergii*.

FIGURE 1
Trends in fish production from inland aquaculture and capture fisheries in Bangladesh from 1994–95 to 2004–05



Source: DoF (2006).

In 2004–5, pond fish production contributed to 85.8 percent of the total aquaculture production, whilst the remainder was produced in coastal shrimp ponds (13.7 percent) and oxbow lakes (0.5 percent). Overall, aquaculture contributed 39.8 percent to the total national fish production (Table 1). Major species-group aquaculture production and species-wise pond fish production during 2004–2005 are shown in Tables 3 and respectively.

In many Asian countries, the increase in aquaculture production is a direct consequence of the expansion of semi-intensive, small-scale pond aquaculture and more appropriate use of feeds and nutrients (Hasan, 2001). This is particularly true for Bangladesh, where the average yield from fish pond aquaculture increased from 0.85 tonnes/ha in 1986 to 2.48 tonnes/ha in 2005 (DoF, 2006). With the exception of a small proportion of aquaculture production from rapidly growing intensive aquaculture systems, the bulk (87 percent) comes from improved-extensive and semi-intensive culture systems. There is great potential to increase the productivity of these systems even further through better use of feeds and fertilizers and even minor increases in production in these systems would significantly raise total fish production. In order to achieve this goal an improved understanding of the production systems, the use of feeds and nutrients and the various aquaculture species is required.

TABLE 1
Aquaculture production from different water resources in Bangladesh, 2004–05

Sources	Area (ha)	Total aquaculture production (tonnes)	Yield (tonnes/ha)	Percent of total aquaculture production	Percent of total fisheries production
Inland fish ponds	305 025	756 993	2 482	85.8	34.2
Coastal shrimp farms	217 877	120 710	554	13.7	5.4
Oxbow lakes[2]	5 488	4 388	800	0.5	0.2
Total	**513 584**	**882 091**		**100**	**39.8**

Source: DoF (2006)

TABLE 2
Major species-group aquaculture production (tonnes) in Bangladesh, 2004–2005

Major groups	Freshwater Ponds	Brackish-water shrimp farms	Oxbow lakes	Total	% of total
Major carps	413 137	-	1 922	415 059	47.05
Exotic carps	236 088	-	1 779	237 867	26.97
Other carps	6 469	-	-	6 469	0.73
Snakeheads	10 738	-	2	10 740	1.22
Catfishes	8 509	-	4	8 513	0.97
Live fishes	6 552	-	1	6 553	0.74
Other fishes	72 940	38 049	669	111 658	12.66
Shrimps and prawns	2 560	82 661	11	85232	9.67
Total	**756 993**	**120 710**	**4 388**	**882 091**	**100.0**

Source: DoF (2006)

TABLE 3
Species-wise pond fish production in Bangladesh, 2004–2005

Major groups	Species	Tonnes	%
Major carps	Rohu (*Labeo rohita*)	163 190	21.56
	Catla (*Catla catla*)	137 685	18.19
	Mrigal (*Cirrhinus cirrhosus*)	112 262	14.83
Sub-total		413 137	54.58
Exotic carps	Silver carp (*Hypophthalmichthys molotrix)*	158 741	20.97
	Grass carp (*Ctenopharyngodon idellus*)	15 897	2.10
	Common/mirror carp (*Cyprinus carpio*)	16 502	2.18
	Java barb (*Barbonymus gonionotus*)	4 693	0.62
	Mixed carps	34 897	4.61
	Others	5 357	0.71
Sub-total		236 088	31.19
Other carps	Orange-fin labeo (*Labeo calbasu*) and kuria labeo (*Labeo gonius)*	6 469	0.85
Snakeheads	Snakeheads (*Channa* spp.)	10 738	1.42
Catfishes	Long-whiskered catfish (*Sperata aor*) and giant river-catfish (*S. seenghala*)	681	0.09
	Wallago (*Wallago attu*) and other catfishes	7 828	1.03
Sub-total		8 509	1.12
Live fishes	Climbing perch (*Anabas testudineus*)	1 892	0.25
	Catfishes (*Heteropneustes fossilis* and *Clarias batrachus*)	4 660	0.62
Sub-total		6 552	0.87
Other fishes	Feather backs (*Notopterus chitala* and *N. notopterus*)	908	0.12
	Olive barb (*Puntius sarana*)	3 179	0.42
	Tilapias (*Oreochromis niloticus* and *O. mossambicus*)	9 992	1.32
	Punti (*Puntius* spp.)	9 008	1.19
	Others*	49 852	6.7
Sub-total		72 940	9.75
Prawns	Giant freshwater prawn (*Macrobrachium resenbergii*), monsoon river prawn (*M. malcolmsoni*) and other freshwater prawn species	2 560	0.34
Grand total		**756 993**	**100**

*All other freshwater fish species not included above. See Annex A1 for details of major groups of aquaculture species in Bangladesh.

Source: Modified from DoF (2006)

[2] Oxbow lakes (local name: baors) are semi-closed water-bodies, cut off from old river channels in the delta of the Ganges.

2. METHODS

This review was undertaken using secondary information from different sources and supplemented, wherever possible, with primary information obtained through farm visits and interviewing of appropriate stakeholders. The primary stakeholders that were interviewed included operators of finfish hatcheries and nurseries, grow-out farmers, operators of shrimp[3] and prawn hatcheries, nurseries and grow-out farmers, fish feed millers, aquafeed companies and feed dealers.

A brief overview of the areas from which the data was collected is presented below and the location of the areas is shown in Figure 2. Geographically, the country is divided into four regions, viz. Northeast, Northwest, Southeast and Southwest and administratively it is divided into 64 districts. The survey covered all four regions.

FIGURE 2
Map of Bangladesh showing the location (red dots) of the areas surveyed for the review

Source: HTTP://WWW.LIB.UTEXAS.EDU/MAPS/MIDDLE_EAST_AND_ASIA/BANGLADESH_POL96.JPG

Rangpur and Dinajpur – these two districts are located in the northwest region of Bangladesh. Aquaculture in these two districts is generally poorly developed, mainly due to the seasonal nature of the ponds. However, semi-intensive carp polyculture is rapidly developing in the area.

Bogra – is located in the northwest region of Bangladesh. This district is particularly well known for the pangas hatcheries that supply juveniles for grow-out to farmers throughout the country.

Mymensingh, Narshingdi and Comilla – located in the northeast region of Bangladesh, these districts have well-developed semi-intensive carp polyculture and rapidly growing intensive pond based pangas nursery and grow-out. Substantial quantities of industrial and farm-made feeds are used in these districts and there are several fish feed mills.

Noakhali and Laxmipur – located in the southeast region of Bangladesh. Semi-intensive carp polyculture is well developed here and there are several new prawn hatcheries and a number of feed mills. Prawn based semi-intensive carp polyculture in ponds and in seasonal lowland rice fields is developing rapidly in these districts. The potential for aquaculture expansion in these districts is high and prawns from where are now being exported.

Cox's bazaar – coastal district located in southeast Bangladesh. It has well developed shrimp hatcheries that supply post larval shrimp to other areas in the country for

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[3] Shrimp primarily refers to the black tiger shrimp, *Penaeus monodon* and includes other marine or brackish-water shrimp species. Prawn primarily refers to giant freshwater prawn, *Macrobrachium rosenbergii* and other freshwater prawn species.

grow-out. Shrimp farming is practised using extensive technologies in large ponds and 'ghers[4]'. There are several aquafeed mills in the district.

Sathkhira District – coastal district located in northwest Bangladesh with well-developed shrimp grow-out farms. Improved-extensive and semi-intensive technologies using industrial and farm-made feeds are employed. The culture of shrimp is carried out in 'and fish feed mills ghers' as an alternate to crop production.

3. AQUACULTURE PRACTICES AND FARMING SYSTEMS

Aquaculture in Bangladesh developed primarily with Indian major carps (*Labeo rohita*, *Catla catla* and *Cirrhinus cirrhosus)* using seed collected from the wild. The sector expanded rapidly with the development of hatchery technologies for Indian major carps and the introduction of exotic carps from China and Europe. Production systems were largely extensive, with limited use of pond inputs. Significant advances in pond management have been made in the last few decades, such that the current array of systems can be classified into three distinct categories, viz. improved-extensive, semi-intensive and intensive systems based on increasing pond inputs, levels of intensification and management (Table 4).

3.1 Semi-intensive polyculture of carps[5]

Semi-intensive systems are the most commonly used aquaculture production systems in the country. The improved availability of seed of various species as well as improved trading networks have enabled these systems to become successful over the last decade.

Overall, the use of feeds and fertilizers in ponds have increased. However, there is considerable variation among farmers with respect to the quantities used and the mode of application. One of the principal objectives of this review was to obtain a better understanding of these variations to develop appropriate strategies for the development of the sector. In particular, cognisance was taken of the high local demand for lower priced fish by poor rural communities. Both poor and marginal farmers practice semi-intensive aquaculture using small ponds or seasonal water bodies. Carp polyculture systems are largely dependent on primary and secondary production through the application of organic and inorganic fertilizers, though fish production can be improved through the application of effective fertilization strategies and supplementary feeding.

3.2 Semi-intensive prawn based carp polyculture

Prawn/carp polyculture has developed rapidly in different areas of the country. In particular this has been facilitated by the improved supply of post-larvae (PL) from newly established hatcheries. Until recently, the major source of prawn seed was from natural waters (Muir, 2003). Hatchery produced PLs fed with formulated industrial feeds in ponds provide healthy juveniles with higher survival rates, improved production and higher profit margins. Recently many low-lying areas have been converted into ponds for prawn and fish culture, particularly in Jessore, Noakhali and Laxmipur Districts. Due to the high price of prawns, their introduction into the carp pond production systems acts as an incentive to use supplementary feed as well as

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4 Ghers are specially designed ponds used mainly for the culture of shrimp and prawns. These have largely developed in the coastal areas of southwestern Bangladesh.

5 'Carps' as used in this review includes the Indian major carps (rohu, *Labeo rohita*; catla, *Catla catla*; mrigal *Cirrhinus cirrhosus*; orange-fin labeo, *Labeo calbasu*) and Chinese carps (silver carp, *Hypophthalmichtys molitrix*; grass carp, *Ctenopharyngodon idella*; bighead carp, *Aristichthys nobilis*). Carp polycultre also includes species such as Java barb (*Barbonymus gonionotus*), common carp (*Cyprinus carpio*), mirror carp (*Cyprinus carpio var. specularis*), Nile tilapia (*Oreochromis niloticus*) and sutchi catfish (*Pangasius hypophthalmus*).

inorganic and organic fertilizers on a regular basis (DoF, 2005; Muir, 2003; Demaine, 2005; Field Survey, 2005).

3.3 Intensive culture of sutchi catfish (local name: Thai pangas), mono-sex Nile tilapia and Thai strain of climbing perch in ponds

The intensive culture of sutchi catfish (*Pangasius hypophthalmus*) (local name: Thai pangas) and more recently, the production of monosex Nile tilapia (*Oreochromis niloticus*) and the Thai strain of climbing perch (*Anabas testudineus*) have developed rapidly, particularly in peri-urban areas in Mymensigh, Narshindi District close to the capital city Dhaka and in the Bogra District. As elsewhere, intensive finfish farming is dependent on a reliable and adequate source of appropriate feeds. Farmers use formulated pellets, manufactured in their own or local cooperative feed mills or purchased from the commercial aquafeed industry. The market price of Thai pangas is lower than Nile tilapia or climbing perch and hence is an affordable protein source for marginal and poor urban people. However, as large amounts of relatively expensive feeds are used the profit margins are lower. This has resulted in a shift towards the production of high-value fish such as mono-sex Nile tilapia, Thai strain of climbing perch and walking catfish (*Clarias batrachus*) (Muir, 2003, Field Survey, 2005).

3.4 Extensive and improved-extensive shrimp culture

The major shrimp culture activities are located in the southeast and northwest regions of Bangladesh (Cox's bazaar, Sathkhira, Bagerhat, and Khulna) and PLs are obtained mainly from hatcheries. Shrimp farming systems in Bangladesh can be generally classified as extensive, in which the shrimp are reared under low-level input conditions and farmers rely mainly on natural pond productivity. The level of production is consequently very low. In recent years there has been a shift towards the greater use of fertilizers and industrial feeds in smaller ghers and these systems are now described as "improved-extensive systems" (Table 5).

The reliable production of PLs in hatcheries now ensures a consistent and adequate supply of seed for the entire production period of around 8 to 9 months. Farmers use

TABLE 4
Characteristics of the different farming systems for carp, prawn and pangas, 2005

Descriptions	Carp polyculture		Prawn culture	Pangas culture
System	Improved-extensive and semi-intensive		Semi-intensive	Intensive
Species	Indian major carps, Chinese carps and common carp	Indian major carps, Chinese carps, common carp, Java barb, tilapia and Thai pangas	Indian major carps, Chinese carps and prawn	Thai pangas, carps and Nile tilapia
Average farm size (ha)	0.05–2.0	0.05–2.0	0.12–0.58	0.97–2.02
Culture period (months)	5–12	5–12	5–8	6–10
Yield (tonnes/ha)	2.0–2.5	2.0–3.0	2.8–3.0	12.0–15.0
Stocking density (per ha)	12 000–15 000	15 000–20 000	10 000–12 000	25 000–30 000
Species ratio	Major carps - 40% Chinese and common carp - 60%	Major carps - 30% Chinese carp, common carp, Java barb - 40% tilapia - 10% pangas - 20%	Major carps - 30% Chinese carps - 40% prawn - 30%	Pangas - 90% tilapia - 10%
Types of feed used with major ingredients	Mixed feed (RB, MOC, WB)	Mixed and pellet feeds (RB, MOC, WB)	Mixed and pellet feeds (RB, MOC, WB, FM, BM)	Pellet feed (RB, MOC, WB, FM, BM vitamins, minerals)
Types of fertilizers used	Cow dung, urea, TSP and lime	Cow dung, urea, TSP and lime	Cow dung, urea, TSP and lime	Lime

Note: RB – rice bran, MOC – mustard oilcake, WB – wheat bran, FM – fishmeal and BM – bone meal

Source: Field Survey (2005)

TABLE 5
Characteristics of the different types of shrimp culture systems, 2002

Description	Extensive	Improved-extensive	Semi Intensive
Potential area (ha)	100 000	55 000	15 000
Shrimp yield (kg/ha/year)	200–400	400–800	1500–3000
Farm size (ha)	>5.0	1.0–5.0	0.5–1.0
Stocking density (PL/m^2)	2–4	5–8	8–15
Culture period (days)	100–120	100–120	100–120
Survival rate (percent)	40–50	50–60	60–70
Average harvest size (g)	35	30	25
Average price (BDT/kg)	350	350	300
Water exchange (time/year)	1	2	3
Expenses (BDT/ha/year)			
Land rent	15 000	20 000	30 000
Pond preparation	5 000	8 000	20 000
Fry	15 000	32 500	57 500
Lime	3 000	5 000	10 000
Fertilizer	100	200	400

US$1.00 = BDT 57.00 [6] (2003 average exchange rate)

Source: Muir (2003)

multiple stocking strategies, under which PLs are stocked at 15–30 day intervals. A recent study by Muir (2003) suggests that improved organic and inorganic fertilization strategies in these smaller systems can lead to a reduction in the use of pelleted feeds.

Farmers have developed several strategies to reduce risk. The most important of these include the practices of multiple stocking and harvesting, stocking of larger juveniles after extensive nursing of PLs and the combined production of shrimp with prawns and carp at low salinity levels. The reduction in risk exposure has encouraged intensification using feeds and fertilizers and has led to an improvement in overall production.

4. FEEDS AND FERTILIZERS USE IN AQUACULTURE

4.1 Organic fertilizers

Cattle and buffalo manure is commonly used as a source of nutrients for fishponds in rural areas of Bangladesh, though the bulk is used for crop farming. The 8.44 million households in the country have a combined total of some 22.29 million cattle and buffalo (BCA, 1996 cited in BBS, 2004). Rural households also rear goats, sheep, chickens and ducks, though the collection of manure from these animals for use as fertilizer is not a viable proposition. On a limited scale, the recent establishment of industrial scale chicken farming provides an opportunity for commercial farmers to purchase and use chicken manure in ponds. The use of biogas as a source of household energy by better-off households with relatively large numbers of livestock is also increasing. The slurry from these biogas plants may also be a good nutrient source for fishponds. A limited number of farmers use compost in fishponds, which is made using crop by-products such as water hyacinth, rice straw, urea (5–10 percent of total compost amount) and lime (2–5 percent). There is considerable potential to increase the production and use of compost in fishponds, though this would require training and raising the level of awareness of the value of compost for pond fertilization.

A recent survey in Mymensingh District revealed that 63 percent of farmers use cow dung, and only 20 percent use compost as pond nutrient inputs. The average application rate was 6.7±6.5 tonnes per ha per year (Karim, 2006). It is well known that the nutrient content of cow and buffalo dung is lower than that of poultry manure and compost (Table 6). However, bovine manure is cheaper and more readily available

[6] Conversion rate of US$ and BDT was for the time when the data were collected. The present conversion rate is US$1.00 = BDT 68.00)

TABLE 6
Nutrient content of different organic manures and their price (BDT/kg, 2005)

Manure	Nutrient content (%)					Price
	Moisture	Nitrogen	Phosphorus	Potassium	Sulphur	
Cow dung (fresh)	60.0	0.50	0.15	0.50	-	0.50
Cow dung (decomposed)	35.0	1.20	1.00	1.60	0.13	0.60
Poultry manure	55.0	1.90	0.56	0.75	1.10	2.00
Compost	40.0	0.75	0.60	1.00	-	2.50

US$1.00 = BDT 65.00

Source: BARC (2005) and Field Survey (2005)

to farmers than chicken litter or compost. For this reason, the promotion of the use of cow and buffalo dung for semi-intensive aquaculture throughout the country has a greater prospect for adoption.

Several different techniques are used to enhance natural productivity in nursery ponds. Farmers who do not have access to adequate quantities of animal manure rely on the decomposition of natural and / or supplementary vegetation in newly inundated ponds to provide organic nutrients for plankton production. Some nursery owners apply mustard oilseed cake to the ponds a few days before stocking to achieve the same effect. The application of manure and slaughterhouse waste to enhance natural productivity of nursery ponds (Field Survey, 2005) is strongly promoted. Mustard oilseed cake and rice or wheat bran are commonly used feeds for fish fry. The non-ingested proportion of the feed also serves as a nutrient source for primary and secondary production.

4.2 Non-conventional organic nutrient sources

a) Solid biodegradable organic waste from urban areas

This includes unused parts of vegetables, fruits, fish, meat, kitchen waste from households, markets, hospitals, restaurants, canteens, food processing plants (both in small towns and in large cities). In most instances this valuable and nutrient rich material is dumped, hence creates unhygienic conditions. Some of this waste could be used effectively and profitably for fish production in peri-urban areas as a source of nutrients as well as supplementary feed. Regular collection and "disposal" of waste in fish ponds would contribute towards maintaining sanitary conditions in urban areas. In order for this to be effectively implemented the awareness would need to be raised among fish farmers, local authorities and the appropriate central government departments.

b) Sewerage waste from urban areas

Urban and peri-urban aquaculture is rapidly developing in many countries and has been stimulated principally by the proximity to markets, access to information and the availability of wastes (Little and Bunting, 2005). Large volumes of sewerage are disposed via drainage canals or accumulate in low land ditches, creating substantial health problems for urban dwellers during the monsoon season when it mixes with run-off water and enters into urban dwellings with floodwater. The problem is severe in large cities and is becoming more and more of a crisis in smaller cities throughout the country. Human waste from urban areas is disposed mainly into rivers and canals via sewerage canals, resulting in the pollution of natural waterways. This neither is a solution to the problem nor is it an acceptable environmental practise. The potential exists to 'harvest' this rich nutrient source for use in crop production and after initial treatment, for fish production (Bunting, Kundu and Mukherjee, 2005; Costa-Pierce *et al.*, 2005). There are some examples of sewerage fed water bodies in urban areas used for the culture of tilapia in Bangladesh. However, these are unplanned and may pose health hazards to workers and consumers (Barman, Little and Janssen, 2003). There is a need for scientific bodies and appropriate government departments to assess the potential of sewerage fed aquaculture and, if feasible, to draw up guidelines for the safe use of human waste in aquaculture.

4.3 Inorganic fertilizers

Nitrogen and phosphorous in the form of inorganic fertilizer are applied to fishponds to stimulate algal growth to increase zooplankton production. Farmers are aware of the benefits of using inorganic fertilizers such as urea, TSP and others. However, despite government subsidies, the use of inorganic fertilizers in aquaculture is limited by its price (Barman, Little and Edwards, 2002; Thompson, Sultana and Firoz Khan, 2005).

The national demand for inorganic fertilizers is estimated by the requirements for crop production. The estimated amount of urea and TSP used by aquaculture is less than 5 percent of national use and hence the requirement of the sector is not considered (Table 7).

Farmers who are intensifying their aquaculture operations are encouraged to use inorganic fertilizers in combination with organic manures and supplementary feeds regularly. However, with experience, further intensification does not necessarily require additional inorganic fertilization. Instead, production can be increased through the application of pig manure as in Viet Nam (Barman, 2005) or through integration with ducks and pigs as in NE Thailand (Edwards and Alan, 2001).

Lime is used to improve water quality and to increase productivity. The present field survey showed that farmers use lime during pond preparation and as a disinfectant prior to the winter months to prevent disease. Farmers who practise intensive pangas aquaculture apply small quantities of lime to their ponds on a monthly basis to improve water quality. Similarly, prawn farmers lime ponds prior to stocking, and at regular intervals thereafter, to facilitate moulting (DoF, 2005, Field Survey, 2005). Several types of lime are available in the market for use in aquaculture and are affordable to the farmers.

Despite the excellent nutrient composition of poultry manure, Banerjee *et al.* (1979) and Knud-Hansen (1998) showed that 1 kg of urea and 1 kg of TSP together contain an amount of available nitrogen and phosphorus equivalent to about 100 kg of chicken manure. In addition, it is a more cost effective source of nutrients (Knud-Hansen and Pautong, 1993). Nevertheless, it remains extremely difficult to convince farmers of the benefits of using inorganic fertilizers.

The increased and improved use of different nutrient inputs in semi-intensive aquaculture systems has almost doubled fish production compared with conventional (improved-extensive) carp polyculture systems (Table 8).

Fish production under semi-intensive culture practices can be improved further by (a) increasing awareness of the effective use of on-farm organic nutrients instead of more expensive off-farm nutrients and feeds; (b) improving the methods of manure and inorganic fertilizer application; (c) increasing the efficiency of the nutrients through improvements of the culture environment and (d) developing strategies and systems to harvest and use nutrients from non-conventional sources such as 'urban organic solid waste' and 'sewerage waste', in a planned manner, for sustainable development of aquaculture.

TABLE 7

Current use, domestic production and inorganic fertilizers imports in 2005–06 (thousand tonnes)

Fertilizer	Use	Domestic production	Imports
Urea	2 875	2 000	875
Triple super phosphate	585	200	385
Single super phosphate	125		125
Di-ammonium phosphate	550	250	300
Gypsum	150		150
NPKS*	117		117
Zinc	30		30

*Mixed fertilizer containing nitrogen, phosphorus, potassium and sulfur

Source: Tofazzal Mia, Deputy Director, pers. comm., DAE[7], Dhaka, Bangladesh

[7] Department of Agricultural Extension, Ministry of Agriculture, Government of Bangladesh

TABLE 8
Use of inputs (tonnes/ha/year) and comparative fish production data in two different culture systems in Mymensigh district, 2005

Production systems	Feed			Organic fertilizer		Inorganic fertilizer			Fish production (tonnes/ha/year)
	Rice bran	Wheat bran	Mustard oil cake	Cow dung	Poultry litter	Lime	TSP	Urea	
Improved-extensive (n=24)	6.83 (5.41)	0.12 (0.37)	0.99 (1.41)	6.55 (5.94)	0.64 (1.21)	0.08 (0.12)	0.04 (0.09)	0.03 (0.03)	2.99 (1.47)
Semi-intensive (n=23)	9.36 (5.29)	0.30 (0.73)	3.2 (1.86)	6.37 (6.58)	1.26 (2.35)	0.14 (0.16)	0.27 (0.25)	0.62 (0.30)	5.83 (1.91)

n= number of farmers; figures in parentheses are standard deviations

Source: Karim (2006)

In the context of the limited availability of feeds, the use of inorganic and organic fertilizers together with supplementary feeding offers the best opportunity to increase total fish production by the large number of small-scale farmers practising semi-intensive carp polyculture. It is, therefore, important for institutions to focus on the improvement of semi-intensive fish culture systems in Bangladesh.

5. FEED INGREDIENTS AND FEEDS

5.1 Cereal products and by-products

A variety of cereals and cereal by-products are either used, singly or mixed, for the feeding of fish in ponds. The most commonly used feed in Bangladesh is rice bran, a by-product of the principal cereal crop of the country. Three common types of rice are grown in Bangladesh, viz. "Boro", "Aus" and "Amon". Boro-irrigated rice is grown in the dry season and harvested before the monsoon (February to April). Aus is grown in the dry season from May to August, while Amon rice is grown during the monsoon season from September to January. Production of Aus is limited compared to other two types. The three types of rice provide a year round supply of bran. National rice production figures from 1997 and 2001 are given in Table 9.

Rice bran comprises five percent of the total rice yield. It is used mainly as feed for cattle and buffalo and is an important ingredient in fish feeds. The nutrient quality and price of rice bran varies depending on its fineness. The bran produced in automated rice mills is finer and has a higher available nutrient content in comparison with bran produced in rural husking mills. Coarse brans are about a quarter of the price of the finer bran. The quality of the bran depends on freshness, storage conditions and duration of storage and because it is a by-product millers normally take less care during collection and storage.

The proximal composition of rice bran varies greatly and depends on the milling process and original quality. Crude protein levels range from 9.8 to 17.2 percent, crude lipid (7.7–22.4 percent), crude fibre (5.7–20.9 percent), ash (7.1–20.6 percent) and nitrogen free extract (40–41 percent). Rice bran is a good supplementary feed and its high calorific value has a protein sparing effect (Xin, 1989). Fish fed on rice bran usually have a high fat content, which is desirable from a human nutrition perspective, as rural, rice-based diets in Asia are typically low in fat (Xin, 1989).

TABLE 9
Production of different types of rice by year in Bangladesh (thousand tonnes), 1997–2001

Year	*Amon* rice	*Aus* rice	*Boro* rice	Total production
1997–1998	8 850	1 875	8 137	18 861
1998–1999	7 736	1 617	10 552	19 905
1999–2000	10 306	1 734	11 027	23 067
2000–2001	11 249	1 916	11 921	25 086

Source: BBS (2004)

Considering the importance of rice bran in animal feeds, or as a single feed, it is important to maintain its quality during production, transportation and storage. Broken rice is also produced as a by-product in rice mills and is used mainly as feed for poultry but also as an ingredient in fish feed.

In recent years the production of maize has increased several fold from 3 000 tonnes in 1997–98 to 64 000 tonnes in 2001–2002 (BBS, 2004). In comparison to rice and wheat, the demand for maize for direct human consumption is low. As a result, there is more scope to use maize for animal feeds, particularly for poultry. The use of maize as an ingredient in fish feed has increased in recent times especially for feeding carp broodfish and during grow-out. It is also used as an ingredient for the manufacture of pelleted feeds for pangas, at inclusion rate varying between 10 to 15 percent by weight. To reduce the cost of fish feeds farmers are inclined to mill their own maize flour for inclusion into feeds rather than purchasing it (Field Survey, 2005).

The production of wheat in 2000–2001 was 1.673 million tonnes. Wheat flour is used mainly for human consumption, though some portion (normally of inferior quality) is used as an ingredient in pelleted fish feed. Wheat flour in small proportions is also used as a feed for fish fry shortly after they are stocked into nursery ponds. The granular form of wheat flour (*suzi*) is used as a feed for prawn PLs a few days after stocking into nursery ponds. Wheat bran is also used a fish feed ingredient.

5.2 Oilseed by-products

Oilseed cakes are important ingredients in fish feeds. Some 376 000 tonnes of various oilseed cakes were produced in 2001–02. The most important seed cakes used in fish feeds are rape and mustard oilseed cake, while groundnut, sesame and coconut seedcake are less commonly used. Rape and mustard accounted for 62 percent, while coconut comprised 23 percent, groundnut 8 percent, sesame sux percent and linseed less than one percent to total fish feed production in Bangladesh. The nutritive composition of the different types of oilseed cake is presented in Table 10.

The results of the field survey suggest that there is a reduction in the use of oilseed cake as a single feed by fish farmers. More often, farmers are now using a combination of ingredients (mustard oilcake, rice bran, wheat bran, maize bran and powder, bone meal, fishmeal, minerals, snail shell powder, vitamins). Pangas and prawn farmers are achieving higher yields using mixed feeds (Field Survey, 2005; Muir, 2003). However, with the expansion of aquaculture activities and the rapid development of intensive culture systems for pangas, tilapia and climbing perch, the overall demand for oilseed cake in Bangladesh is increasing. Maintenance of oilseed cake quality during production and storage is also important for its effective use.

5.3 Pulse powder and by-products as fish feed

Other than for direct use in human nutrition, powdered pulses and by-products (bran) are largely used as livestock feed. Use of pulse powder (*basan*) in small proportions in formulated pellets for Pangas has been reported. However, the scope for the use of pulses is limited as the traditional production areas are now used for the cultivation of rice and other crops.

5.4 Weeds/grasses and plant by-products as fish feed

Duckweed is commonly used as feed for Java barb and grass carp, which grows prolifically in low land rice fields, mainly during the monsoon season, coinciding with the fish production period. The collection of duckweed is labour-intensive. In Jessore, poor people collect duckweed for sale to fish farmers (Field Survey, 2005). Generally, it grows faster in ditches or small derelict water bodies that are connected to household drainage systems where there is a good supply of nutrients.

Grasses in wetland areas are used as a source of feed for grass carp, as are banana leaves (BBS, 2004). Water hyacinth is a common aquatic weed but its use as a fish feed is limited, due to its poor palatability. By-products of vegetables such as unused leaves of cabbage and radish could be used as fish feed but the production of these vegetables largely takes place during winter months when fish require less feed. However, the development of early variety of cabbage has the potential to be used as an input in fish feed due to its high production volumes, extended seasonal availability and low price.

5.5 Fish feed from animal sources

5.5.1 Fishmeal

Fishmeal in Bangladesh is made from trash fish and other marine aquatic animals. However, it is important for the authorities to recognise the importance of this fish for direct human consumption, instead of reducing it for the production of animal feeds.

Fish feed millers generally use industrial fishmeal, though some purchase trash fish and other by-catch species for the manufacture of their own fishmeal. The Bangladesh Fisheries Development Corporation (BFDC) has four fishmeal production plants with a capacity to produce eight tonnes/day (Murtuza, 1998). Industrial fishmeal contains around 56 percent protein, 20 percent lipid and 2 percent crude fibre (Table 8). The amount of trash fish used in aquaculture in Bangladesh ranges between 5 000 and 70 000 tonnes/year (NACA/FAO, 2004).

Dried fish is more readily available at the coast than in inland areas. A more equitable distribution of fishmeal to facilitate the manufacture of animal and fish feeds was addressed by a Danida (Danish International Development Assistance) supported project. The project provided transportation facilities for the movement of dried fish, which due to its smell is normally not permitted on public transport. This created a win-win situation whereby the feed producers had access to good quality dried fish, while the producer received a better price by selling their dried product directly to the users instead of an intermediary. By linking the local feed factories directly with the producers of dry fish enabled the factory to provide quality feeds at a competitive and affordable price for the farmers (Harvey, 2005).

5.5.2 Bone and meat meal

The use of bone and meat meals in fish feed has recently increased as an alternative to fishmeal. Large, though unspecified, quantities of bone and meat meal are now imported from several countries such as Croatia, Denmark and Belgium. The protein content of meat meal and bone meal ranged from 40–55 percent (Field Survey, 2006).

5.5.3 Other sources of animal protein as feed ingredients

Alternative animal sources include shrimp meal, blood meal and silkworm pupae. However, the availability of these resources is limited such that their possible use in fish feeds is at best marginal. For example, shrimp heads are used directly for human consumption.

6. FEEDING PRACTICES IN RELATION TO FARMING SYSTEMS AND SPECIES, FARM-MADE FEEDS AND NUTRIENT MANAGEMENT STRATEGIES

6.1 Carps

Broodstock feeds

Two to three months prior to breeding, carp broodstock are fed a mixed, high protein feed. The composition of the feed is variable but normally consists of mustard oilcake (40 percent), rice bran/rice polish (20 percent), wheat bran (30 percent), fishmeal (9 percent) and vitamin premix 1 percent at 2 percent body weight per day. Other ingredients that may be incorporated into the broodstock maturation diet include molasses, corn flour, meat and bone meal, and fishmeal (Field Survey, 2005). Feed is delivered as 'wet balls' placed in one or two specific places within the pond. To increase the availability of natural feed cow dung at 250 kg/ha, urea at 50 kg/ha and TSP at 25 kg/ha are applied after mixing with water.

Larval feeds

Feeding of carp larvae starts after yolk sac absorption (32–48 hours after hatching depending on temperature). The larvae are commonly fed on hardboiled chicken or duck egg yolk. Two egg yolks suffice for 0.4–0.5 million larvae. The egg yolk is mixed with water, spread over the rearing tanks, and applied four times daily at six hourly intervals until 4–5 days after hatching, after which they are offered for sale. Zooplankton (rotifers and cladocerans) are the main natural food items of the larvae in nursery ponds. To enhance zooplankton production farmers fertilise their ponds in various ways. The most commonly applied fertilizers are cow dung, urea and TSP at variable rates (Saha *et al.*, 1989, Miah *et al.*, 1996), depending on availability. Goat litter and fermented / decomposed mustard oilseed cake can also be applied prior to stocking. It is generally recommended that the litter of one goat is adequate for 40m^2 pond surface area or 85 kg/ha of decomposed oilseed cake.

TABLE 10

Chemical composition (percent dry matter) of major feed ingredients in Bangladesh

Ingredients	Dry matter	Crude protein	Crude lipid	Ash	Crude fibre	NFE[1]	Gross energy (kcal/kg)
Feed ingredients of animal origin							
Fishmeal	91.8	56.4	19.7	19.5	2.2	2.2	4 365
Fish silage	90.1	56.8	7.5	12.2	6.5	17.0	5 432
Blood meal	90.8	92.9	0.3	6.3	0.5	-	4 250
Silkworm pupae meal	91.2	61.1	24.8	6.7	4.3	3.2	5 939
Poultry offal meal	89.8	75.5	16.3	7.3	1.0	-	
Bone meal	92.5	17.5	5.2	65.7	3.5	8.1	1 988
Meat and bone meal[2]	90.9	55.6	12.34	29.7	NA[3]	-	
Protein concentrate[4]	91.6	61.0	11.5	18.1	NA	-	
Feed ingredients of plant origin							
Soybean meal	91.4	45.2	20.5	6.2	5.0	23.1	
Sesame meal	92.0	33.3	8.4	14.9	24.0	19.5	4 743
Mustard oil cake	93.0	36.5	11.2	9.2	11.6	31.5	4 978
Linseed meal	90.9	39.0	6.7	12.8	9.1	32.5	4 386
Coconut oil cake	95.5	18.2	10.2	6.5	11.7	53.5	4 723
Cotton seed meal	87.6	35.7	17.1	6.1	18.3	22.8	
Cotton seed oil cake	90.9	22.7	6.2	11.7	29.9	29.5	
Rice	87.4	8.4	2.1	1.0	1.6	86.9	
Rejected broken rice	86.6	10.6	2.1	2.2	3.1	82.1	
Rice bran	90.0	12.6	16.5	13.6	16.3	40.9	4 235
Wheat bran	88.5	18.2	4.4	4.8	14.0	58.6	4 488
Wheat flour	93.2	12.5	1.3	2.1	2.1	75.6	4 488
Broken maize	87.9	11.3	5.0	2.5	2.8	78.4	
Lentil bran	84.3	19.5	0.5	7.3	25.9	46.9	4 286
Black gram bean meal	12.9	18.8	0.6	7.5	22.8	50.5	4 252
Mung bean bran (green gram)	87.9	8.1	2.9	10.6	37.5	41.0	
Grass pea bran	87.5	11.0	1.8	8.1	38.8	40.4	
Black gram bran	87.5	17.9	2.4	7.4	24.3	48.0	
Field pea bran	89.2	11.4	1.0	5.8	39.6	42.3	
Leucaena meal (unsoaked)	90.0	27.2	6.3	6.6	19.4	40.5	
Leucaena meal (soaked)[5]	90.2	29.6	5.3	4.4	18.8	41.9	
Water hyacinth leaf meal	94.3	25.6	1.1	11.7	17.2	44.4	4 031
Duck weed meal	94.9	17.6	1.4	38.1	8.1	34.8	3 969
Molasses	31.7	4.5	0	11.9	0	83.6	3 624

[1]NFE = Nitrogen free extract; [2]imported, country of origin Australia; [3]NA = not analyzed; [4]imported, country of orgin USA; [5]leucaena leaves were soaked in water at ambient temperature (25–28^{0}C) for 48 hours to reduce the mimosine content of the leaf

Source: Hasan, Alam and Islam (1989); Zaher and Mazid (1994); Hasan, Roy and Akand (1994); Hossain (1996); Faruque (2006)

TABLE 11
Feeds used in carp nursery ponds, 2005

Type of feed	Duration (days)	Amount of feed (x weight of hatchlings stocked)	Frequency of feed use (no./day)
Wheat flour	3	3*	3
Wheat flour and mustard oilcake**	4	4	2
Mustard oilcake and rice bran	7	5–7	2
Mustard oilcake, rice bran/wheat bran	7	8–10	2

*Amount of feed used = 3 times the weight of the hatchlings stocked, **Ratio of ingredients in all feed mixtures are usually 1:1.

Source: Field Survey (2005)

Nursery management

To improve survival and growth, carp nursery ponds are limed (250 kg/ha) and fertilised (cow dung 5 – 7 tonnes/ha, urea 50 kg/ha and TSP 25 kg/ha) prior to the introduction of early juvenile fish. An insecticide (sumithion or dipterex) is also applied 16–24 hours before stocking to remove insects and larger zooplankton that may predate on the larvae. After stocking, the larvae are fed at regular intervals for 3 weeks until the late juvenile stage (Field Survey, 2005) (Table 11).

At the end of the three-week nursery period, the fry are transferred to separate ponds at a lower density (thinning out) and grown to fingerlings for sale. During this period, they are normally fed a diet consisting of mustard oilcake (50 percent) and rice bran/wheat bran (50 percent) at a rate of 10–12 percent of body weight per day and fed twice daily. In addition, inorganic and organic fertilizers such as cow dung 275–500 kg/ha, urea 8.5 kg/ha and TSP 5.0–6.2 kg/ha are applied at weekly intervals. Before application, cow dung and TSP are soaked in water overnight. Urea is then added and the mixture is applied to the pond before noon.

Carp grow-out systems

Carp grow-out is practised either under "improved-extensive" (in flooded rice fields or oxbow lakes) or under semi-intensive culture conditions in ponds. In the semi-intensive systems, feeds are used to supplement natural food to achieve higher yields. Generally, several carp species are farmed under polyculture conditions and this has been strongly promoted throughout the country. Semi-intensive polyculture of carp has yielded good results in communal ponds where the water is used for various purposes, particularly in rural areas of Bangladesh (ADB, 2005). Studies in the districts of Kapasia and Sreepur revealed that the average level of pond inputs were similar to those recommended by the extension services with the exception of lime, which many did not apply before stocking. The majority of pond owners use cow dung from their own sources and about 50 percent of farmers used urea. Rice bran is used as a supplementary feed by most farmers and is purchased from the local market. Where affordable, farmers also use mustard oilseed cake (Thompson, Sultana and Firoz Khan 2005).

Several feeding methods are used by farmers in rural areas. Farmers will either feed their fish on a daily basis by spreading the feed over the surface, while others fill perforated bags with a mixture of mustard oilseed cake, wheat bran and auto rice bran[8]. These are suspended in the water using bamboo poles for 7–10 days rather than applying feed on a daily basis. Alternatively, ingredients such as mustard oilseed cake (50 percent) and rice/wheat bran (50 percent) are mixed and kneaded into wet dough and fed to the fish every 3 to 4 days at a rate of 2–3 percent of body mass twice per day, in the morning and evening. Most of the more entrepreneurial farmers use semi-

[8] Rice bran produced from automatic rice mill. These rice brans are finely milled and have a better nutrient content.

TABLE 12
Feed and fertilizer use, production and income of entrepreneurial carp polyculture farmers in different areas in Bangladesh, 2005

Categories/types	Specifications
Pond area (ha) (mean± SD)	2.1±2.0
Species (polyculture)	Indian major carps, Chinese carps, Java barb, common carp and pangas.
Fertilizers	Lime, cow dung, urea, TSP
Feed ingredients (proportion in the feed)	Rice bran 20–50%, oilcake 25–70%, maize 10–50% and wheat bran 10–50%
Feed ingredients used (% of respondent)	Rice bran 60%, oilcake 100%, maize 65%, wheat bran 20%
Feeding frequency (times per day)	Once (most common) Once every alternative day (rarely)
Amount of feed used per farmer (kg/day)	10–35
Culture period (months)	5–12
Total feed use (tonnes) (mean ± SD)	3.2±2.1
Total expenditure for feed (BDT) (mean ± SD)	35 000±17 000
Price of feed (BDT/kg)	7.00–10.00
Total fish production (tonnes) (mean ± SD)	6.2±5.8
Yield of fish (tonnes/ha) (mean ± SD)	3.6±1.1
Price of fish (BDT/kg)	38.00–55.00
Total income per farmer (BDT/year)	90 000–1 200 000

SD = standard deviation; US$1.00 = BDT 65.00
Source: Field Survey (2005).

intensive systems of production with higher levels of organic and inorganic fertilization and supplementary feeding. Their yield and income is significantly higher than that of the average farmer (cf. Tables 4 and 12).

6.2 Pangas

Hatchery and nursery

Pangas hatcheries are located mainly in the Bogra District in northern Bangladesh. Pangas fry and fingerling production has developed into a major activity in this area at the expense of carp hatcheries. This change has been brought about mainly by the higher price for pangas seed and improved transport and communication infrastructure. Pond area of pangas hatcheries ranges from 0.2–6.2 ha, while the total amount of feeds used for the management of broodfish varies from 5–40 tonnes per annum per farm. Feed expenditure amounts to between 60 and 70 percent of total hatchery expenditure. The hatcheries produce up to 20 million pangas hatchlings per season. Some of the hatcheries also produce hybrid catfish seed. There have also been substantial advances in pangas broodstock management. Instead of only using mustard oilseed cake and bran, farmers now use mixed feeds containing up to 11 different ingredients (Table 13). This has resulted in improved seed quality and survival (Field Survey, 2005).

TABLE 13
Composition of pangas broodstock feed in Bogra District, 2005

Ingredients	Proportion in feed mixture (%)		Price (BDT/kg)
	Minimum	Maximum	
Rice bran	30	91	11.0
Mustard oilcake	1	10	12.0
Corn flour	3	10	11.0
Broken rice	0	10	7.5
Pulse flour	0	5	40.0
Wheat bran	4	10	12.0
Fishmeal	2	10	32.0
Bone meal	2	5	10.0
Salt	0	3	10.0

US$1.00=BDT 65.00
Source: Field Survey (2005)

Pangas larvae and early juveniles are reared in aluminium trays on mixed feeds using ingredients such as egg yolk, wheat flour, pulse powder, refined dried fish powder and vitamin premix. Some hatcheries also feed the larvae on a paste consisting of rotifers, egg yolk and fresh fish, at two hour intervals (Field Survey, 2005). For the first 15 days after stocking the early juveniles are fed on wheat flour mixed with eggs and then on mixed feeds (rice bran, boiled broken rice, corn flour, wheat flour, mustard oilcake and vitamin premix). Only some farmers use commercial pelleted feeds for fry nursing. Pangas fingerlings in the Bogra district are sold when they are 2 to 3 cm in length. Farmers purchase seed directly from the hatcheries, generally in large numbers of at least 0.2–0.3 million at a time and stock them in their own nursery ponds before transferring them to grow-out ponds. Purchasing seed of this size reduces transport stress and mortality. In the (secondary) nursery ponds they are fed either on commercial pelleted feeds or farm-made, mixed, non-pelleted feed.

Pangas grow-out systems

The grow-out of pangas is mainly pond based. Fingerlings are stocked at between 25 000 and 75 000 fingerlings/ha. Grow-out periods range from 5–6 months to 8–10 months. For optimum feed utilization the fish are grown in polyculture with several carp species and Nile tilapia. This practise also increases production and income. Pangas production largely depends on the use of formulated pelleted feeds, though farm-made feeds are also used. Consequently, there are numerous local feed mills in the pangas farming areas. The reported annual yield in Mymensingh and Comilla districts is in the region of 27 tonnes of pangas, four tonnes of tilapia and one tonne of carps per ha/year. The ingredients used for pangas pelleted feeds vary widely between farmers and amongst industrial pellet manufacturers. Normally 7– 8 types of ingredients are used. Fine rice bran from industrial rice mills, mustard oilseed cake, wheat bran, fish, squid or crustacean meal and wheat flour are the major ingredients. In addition, maize flour, snail or mussels shell powder, bone or meat meal, vitamin and mineral premix are also used (Field Survey, 2005). Ration size, the types of feed, price, feeding frequency and food conversion ratio's are illustrated in Tables 14 and 15.

The market has responded positively in supplying the increasing demand for fish feed ingredients and compound feeds. Farmers are able to obtain several different ingredients directly from local markets or from feed millers. Some farmers use their own pellet making machines, while others, who do not own the necessary machinery, supply the ingredients to millers who prepare the feeds to their specifications (Figure 3). Farm-made feeds and feeds produced by local millers are cheaper than the industrially available feeds (Figure 4). However, many

TABLE 14
Pangas rations during the grow-out cycle in ponds in Trishal, Mymensingh, 2002

Size of fish (g/fish)	Ration (% body weight)
<100	15–20
100–150	10
151–500	5
>500	3

Source: Muir (2003)

TABLE 15
Feeds used in pangas grow-out in Mymensingh, Narshindi, Comilla and Dinajpur districts, 2005

Type of feed	Source	Price (BDT/kg)	Feeding frequency (no./day)	FCR
Commercial pellet feed	Commercial aquafeed industry	16–22	2	1.8–2.0
Commercial Pellet feed	Small local feed manufacturers	14.00	2	2.0–2.2
Pellet feed	Farm-made or made in rice mill facilities	12.00	2	2.0–2.5
Mixed non-pelleted feeds	Farm-made	5–10	2	-

US$1.00 = BDT 65.00

Source: Field Survey (2005)

FIGURE 3
Ground mixed feed ingredients ready for pelleting in a small pellet machine

COURTESY OF BIBHU BHUSAN MOJUMDAR

FIGURE 4
On-farm pelleted feeds ready to be applied to pangas ponds

COURTESY OF BIBHU BHUSAN MOJUMDAR

farmers are aware of the nutritional requirements of the fish such that fish production using farm-made feeds is often inferior to that achieved using industrial pellets. Semi-intensive pangas culture has also developed in areas outside of the traditional clustered pangas farming areas as in Mymensingh, Narshingdi, Tangail, Kishorgonj and Bogra districts. Farmers in these areas, e.g. Dinajpur and Comilla Districts use mainly farm-made feeds composed of various combinations of rice bran, maize powder, oilcake, boiled broken rice, biogas slurry and occasionally dry fish powder, vitamins and mineral premix. The price of feed varies between BDT 5.00–8.00/kg. Similar to their counterparts elsewhere, farmers in the more isolated pangas growing regions also use lime during pond preparation as well as urea and TSP at regular intervals. Production costs are lower in the more isolated areas than in the clustered areas, though production per unit area is lower at approximately 5 to 8 tonnes/ha/year.

6.3 Shrimp

Shrimp hatcheries and nurseries

The production of shrimp post-larvae (PL) in hatcheries is very successful and supply reportedly exceeds demand. It is important to note that most of the high cost feeds used for larval rearing is imported. Almost all hatcheries purchase brood shrimp from trawlers, varying in size from 60–150g and price from BDT 1500 to 2500 per piece. After capture, they are kept in broodstock rearing tanks for 5–7 days until the gonad maturation process is completed. During this period they are fed on mixed feeds consisting of crab muscle, cow liver, squid muscle and mussel meat as well as formulated feeds. Most of the hatcheries use algae, produced in their own facilities, to feed the larvae as well as other types of plankton purchased on the market. Various imported feeds, including *Artemia*, (Table 16) are used for PL rearing. Annual production of PLs varies from 100–300 million per hatchery.

TABLE 16
Feed used for final maturation of shrimp broodstock, larval and post-larval rearing in hatcheries at Cox's bazaar, 2005

Shrimp	Type of feeds	Price of feed (BDT/kg)	Amount and feeding frequency
Broodstock	Crab muscle, cow liver, squid muscle, mussel meat	Crab 40–45, Cow liver 120, squid 70–90 and mussel meat 40–45	10% of body weight of shrimp, applied 4 times/day
Larvae	Algae (diatom) and other commercial feeds	Algae from own source and *Spirulina* powder 3 000	6 times/day until post-larval stage
Post-larvae	*Artemia* nauplii 40%, brine shrimp flake and mixed feed 60 %	*Artemia* 3 500, brine shrimp flake 1 500 and mixed feed 400	15–16 days after reaching post-larval stage in nursing tanks

Source: Field Survey (2005)

There are no facilities dedicated solely to PL nursing. Nursing is carried out in small sections of the gher for a short period (PL $_{11–15}$). These are called pocket nurseries. PLs are stocked in the pocket nurseries for 4–7 days whereafter the outlet is opened and PLs are allowed to enter into the gher. The process of stocking PLs in the pocket nurseries and then transferring them to grow-out facilities is normally repeated at 15 day intervals and continued throughout the production season from February to September. Before stocking PLs into the pocket nurseries (≈ 0.04 ha), 500g bleaching powder, 4 kg lime, 2 kg urea and 1.5 kg TSP are applied. Within 5–6 days of urea and TSP application, the colour of the water becomes light green and is then ready for stocking of PLs. In the pocket nurseries formulated granular powdered feeds are used (e.g. Tiger brand feed of CP Feed Ltd.). The feed contains 42 percent protein, 8 percent lipid and 10 percent moisture. The amount of feed used is 200g for every 0.1 million PLs twice per day at 07.00 and 19.00 hours. The price of granular feed is around BDT 75.00/kg. The feed is moistened before use and applied by spreading it along the shallow ends of the nursery pond. Wheat flour was used previously even though mortalities often reached 50 percent. The use of formulated granular feed has significantly increased the survival rate of PLs.

Shrimp grow-out systems

Shrimp grow-out in large gher systems in both Cox's bazaar and Sathkira is an extensive operation and production depends almost entirely on fertilization and natural food, with a limited measure of supplementary feeding. Shrimp production in large gher's rarely exceeds 150 kg/ha. Previous studies on shrimp grow-out (Muir, 2003) also reported low levels of pond inputs. Sixty four percent of farmers applied small quantities of pre-stocking inputs and only 41 percent applied some form of post-stocking inputs, such as lime, urea, cow dung, rice/wheat bran, fishmeal and oil cake (Muir, 2003). The recent field survey confirmed these findings. Farmers who use small to medium size ghers have adapted their technologies to a semi-intensive scale of operation. The size of large ghers located in Cox's Bazaar and Sathkhira Districts vary between 32 and 138 ha. In this area shrimp culture is alternated with salt production and the culture period is 6–7 months. In Sathkhira, the ghers are used only for shrimp production. PL stocking densities vary from 0.7–3.1/m^2. The first harvest occurs 3 months after stocking, when the shrimp range in size form 100 to 65g (10–15 shrimp/kg). At such a size the price varies from BDT 400–600/kg and production varies from 63–150 kg/ha. Large ghers are generally prepared using lime at 31 kg/ha and cow dung at 250 kg/ha. Inorganic fertilizers such as urea (@ 2.5–5.0 kg/ha) and TSP (2.5 kg/ha) are diluted and spread throughout the gher area by boat and applied at one month intervals. Rice bran or wheat bran at 5–6 kg/ha is used as supplementary feed. The bran is soaked in water for 12 hours before it is applied in the evenings at 8 – 15 day intervals.

Small and medium ghers vary in size between 0.67 and 2.67 ha. They are used for monoculture of *P. monodon* or polyculture of shrimp in combination with *M. rosenbergii* and several carp species. Production is higher than in the large ghers and ranges from 500 to 1000 kg/ha under monoculture and polyculture conditions, respectively. Rice and wheat bran, mustard oilseed cake and commercial pellets are used as feed, though the amount and frequency of feeding varies greatly amongst farmers. All farmers with small and medium size ghers use organic and inorganic fertilizers, including cow dung, poultry droppings, urea and TSP to increase natural productivity. Lime, urea and TSP are used as pre- and post-stocking inputs (Table 17).

TABLE 17

Use of organic and inorganic fertilizers in small and medium size ghers per grow-out cycle, 2005

Input	Pre-stocking (kg/ha)	Post-stocking (kg/ha)
Lime	63–250	15–62
Urea	6–42	6–125
TSP	0–15	30–37
Cow dung	4 000	
Poultry dropping	1 250	

Source: Field Survey (2005)

6.4 Prawns

Hatcheries

Prawn hatchery operators use formulated granular feeds produced by local feed manufacturers for the production of post-larval *M. rosenbergii*. The prawn broodstock is stocked in separate ponds four months before use in the hatchery and are fed regularly with granular feeds at a rate of 6 percent body weight, twice a day. Feeding trays are used to check and adjust the amount of feed required. A proportion of feed is also applied outside the trays to ensure feeding of all prawns in the pond. To induce the broodstock to feed more, the granular feed is alternated with farm-made feeds for 1–2 days at 15–20 day intervals. These farm-made feed generally include auto rice bran (30 percent), wheat bran (10 percent), mustard oilseed cake (25 percent), fishmeal (30 percent) and molasses (5 percent).

Twelve hours after hatching the larvae are fed *Artemia* nauplii, at a rate of 25g Artemia per 200 000 larvae for the first 10 days, whereafter the feeding rate is doubled until day 30. The Artemia is supplemented with farm-made chicken or duck egg custard. After 30 days the PLs are ready for sale. The greater proportion of prawn PLs used in Bangladesh are however still collected from the wild, so there is great potential for the development of additional prawn hatcheries. However feed costs are high and this calls for the development of alternative cheaper feeds.

Nursing of post-larvae

Laxmipur and Noakhali Districts are the major prawn nursery areas. The duration of the nursery period ranges from 1–3 months and farmers normally use small (0.02 to 0.07 ha), shallow (90 – 100cm) ponds as nurseries, which are integrated with crop farming in one way or another. PLs are stocked at a density of 25–35 PLs/m^2. All nursery operators apply lime to their ponds as a pre- and post-stocking management strategy at 150–250 kg/ha and 13–150 kg/ha, respectively. Some also use cow dung at 250–800 kg/ha, urea at 13 kg/ha and TSP 13.0 kg/ha but only as pre-stocking inputs. During the nursery period the juvenile prawns are fed on a variety of feeds, such as wheat flour (local name: *suzi*), broken rice or mixed feeds (mustard oilcake, wheat bran, wheat flour and fishmeal) as well as farm-made pelleted or commercial feeds. Higher survival rates are obtained with the use of formulated pelleted feeds.

TABLE 18
Formulation (%) and price (BDT/kg) of low cost prawn diets

	Diet 1			Diet 2			Diet 3		
Ingredient	Inclusion (%)	% protein	Price (BDT/kg)	Inclusion (%)	% protein	Price (BDT/kg)	Inclusion (%)	% protein	Price (BDT/kg)
Fishmeal (local)	15	9.34	3.75	15	9.34	3.75	10	6.23	2.50
Meat and bone meal	-	-	-	8	4.09	1.52	5	2.55	0.95
Full-fat soybean	10	4.29	1.70	-	-	-	10	4.29	1.70
Mustard oilcake	15	5.65	2.10	15	5.65	2.10	14	5.27	1.96
Maize	15	1.45	1.65	15	1.45	1.65	20	1.93	2.20
Rice bran	25	1.98	2.13	27	2.14	2.30	12	0.95	1.02
Wheat bran	10	1.72	1.10	10	1.72	1.10	19	3.28	2.09
Wheat flour	5	0.64	0.75	5	0.64	0.75	5	0.64	0.75
Molasses	4	-	0.40	4	-	0.40	4	-	0.40
Salt/shell powder	1	-	0.10	1	-	0.10	1	-	0.10
Total	**100**	**25.06**	**13.68**	**100**	**25.02**	**13.67**	**100**	**25.13**	**13.67**

US$1.00 = BDT 65.00

Source: Hossain (2006)

TABLE 19

Calculated proximate composition and gross energy (kcal/100g) content of the three low-cost prawn diets (percent dry matter basis)

Components	Diet 1	Diet 2	Diet 3
Crude protein	25.1	25.0	25.1
Crude lipid	10.8	9.8	9.6
Carbohydrate	39.2	37.9	40.2
Gross energy (kcal/100g)	396	383	390
Price (BDT/kg)	13.7	13.7	13.7

Source: Hossain (2006)

Prawn grow-out

Prawn grow-out is generally undertaken in polyculture with several carp species (rohu, catla, mrigal, grass carp and Java barb) under improved-extensive and semi-intensive conditions. Farm-made pellets are normally used and these are made using mustard oilseed cake (20 percent), fine rice bran (20 percent), wheat flour (8 percent), dry fish powder (20 percent) and molasses (2 percent). The cost of on-farm pelleted feed is cheaper than commercially produced pelleted feed. The mixed non-pelletized feeds include rice bran, wheat and mustard oilseed cake in various proportions. Farmers are of the view that it is beneficial to use both pelleted and non-pelleted feeds. Only a small proportion of farmers use factory made pelleted feeds. The Danida supported project at Noakhali and Potuakhali in northern Bangladesh suggested that farmers use one of three formulations for the preparation of farm-made feeds (Table 18). The nutrient content of these feeds are tested at the Bangladesh Agricultural University Laboratory (Table 19). This is a good example of extending the practical role of an academic institution to meet farmer needs (Masum, 2005). Average production figures range between 575 and 1050 kg/ha for prawns and from 500 to 1 760 kg/ha for mixed fish.

Some farmers also use non-conventional feeds such as snail meat. However, the rapid expansion of prawn farming makes this practise unsustainable. For example, in Bagerhat the improved farm-made feeds has resulted in a significant decrease in the use of snail meat by 34 percent from 164 192 tonnes in 1998 to 22 774 tonnes in 2000 (Islam, 2001). There is a definite move towards the intensification of prawn grow-out systems. Most of the recently established farms are smaller (0.1 to 0.6 ha of pond area) and these are used on a seasonal basis (5–6 months of the year) and alternated with crop production. Farmers with perennial ponds generally extend the grow-out period for up to 10 months.

As a pre-stocking management strategy farmers apply lime at 125–250 kg/ha, cow dung and / or compost at 2–5 tonnes/ha. Lime is also applied two to three times during the production season at 50–100 kg/ha. Lime is applied by diluting it in water and spreading the liquid mixture over the water surface of the gher. Urea at 25 kg/ha and TSP 20 kg/ha are occasionally also applied at certain intervals as post-stocking inputs.

As mentioned above, prawn farmers who previously practised carp polyculture have increasingly adopted mixed prawn and fish culture. The underlying reason for this is the added benefit of prawns, which are exported. Overall, this has resulted in better managed systems, improved production and higher profit margins.

7. DEVELOPMENT OF THE AQUAFEED INDUSTRY

The increasing demand for formulated aquafeeds has resulted in the establishment of dedicated feed companies. This development is largely linked to the intensification of aquaculture in some areas of the country. Imported feeds from Europe, the United States of America, Japan and Taiwan Province of China are mainly those used in shrimp and prawn hatcheries. Mineral and vitamin premixes are also imported.

The aquafeed industry in Bangladesh has its origins in the poultry feed industry. Presently there are some 14 aquafeed manufacturers in the country (Kader, Hossain

FIGURE 5
Workers involved in making pellets in a small-scale fish feed mill at Narshindi Sadar, Narshindi, Bangladesh

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FIGURE 6
Common feed ingredients used for making pellet feed

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and Hasan, 2005); Field Survey, 2005). Most of the manufacturers are involved in the production and supply of feeds for finfish culture and principally for pangas farming, though some are now also producing feeds for shrimp and prawns. Six types of feeds are produced for shrimp (Nursery, Starter 1, Starter 2, Starter 3, Grower and Finisher) and seven different formulations are produced for pangas farming (Pre-nursery, Nursery, Starter 1, Starter 2, Starter 3, Grower 1 and Grower 2) (Field Survey, 2005).

The industry is currently unregulated with respect to quality assurance. However, policy guidelines are presently being developed by MOFL to regulate the industry so that feed quality can be assured (DoF, 2005). The significant differences between the factory quoted proximate composition of feeds and independent laboratory tests (Kader, Hossain and Hasan, 2005) emphasises the urgent need to develop a system for quality assurance for the greater benefit of farmers.

Coupled with the development of the commercial aquafeed industry there has been a marked increase in the production of compound farm-made feeds and a proliferation of small-scale feed mills in aquaculture intensive districts throughout the country (Figure 5).

Many of the small-scale feed millers simply provide a service by making pellets with ingredients supplied by the farmer. Dry fish, oilseed cake (mainly mustard but also sesame and soybean), fine rice bran, wheat flour maize, molasses, bone meal, mussel shell powder and vitamin premix are the main ingredients (Figure 6) of locally produced aquafeeds in the small-scale, micro-enterprise mills. The most common formulation is dry fish (30 percent), oilseed cake (23 percent), fine rice bran 25 percent), wheat flour (7 percent) and others (15 percent). The current manufacturing cost (milling, mixing, pellet making and drying) is BDT 800/tonne.

7.1 Aquafeed use in Bangladesh

Although based on limited information some 50 000 tonnes of feed are produced per annum by the industrial aquafeed industry, mainly for intensive culture (hatchery, nursery and grow-out) of pangas, mono-sex Nile tilapia and Thai strain of climbing perch. Shrimp and prawn feed production amounts to around 10 000 tonnes per annum (Table 20). Other than the industrially produced aquafeeds, a substantial quantity of pelleted feed for pangas and shrimp and prawn are either farm-made or produced by small-scale feed manufacturers. Estimates of total aquafeed use and its origin are presented in Table 20. Overall, some 230 000 tonnes of aquafeeds are used per annum.

Of interest are the relative proportions of feed use by the relatively small number of intensive fish farmers in comparison with the farmers who employ improved-extensive and semi-intensive technologies. In the improved-extensive and semi-intensive farming systems (see above) production is largely reliant on fertilization and natural pond productivity, with limited supplementary feeding. It is estimated that approximately

TABLE 20
Estimated amounts of feed use for aquaculture production in Bangladesh, 2004

Production systems/species	Industrial pellets (tonnes)	On-farm pellets & mixes (tonnes)	On-farm mixed feed (tonnes)	Total (tonnes)
Pangas, tilapia and climbing perch	50 000	40 000	10 000	100 000
Shrimp and prawn	10 000	20 000		30 000
Carp polyculture for food fish	-		80 000	80 000
Carp seed production	-		20 000	20 000
Total	**60 000**	**50 000**	**100 000**	**230 000**

Source: Field Survey (2005)

89 percent of the total annual aquaculture production of >900 000 tonnes in Bangladesh is produced by the latter group of farmers. Assuming that 100kg of supplementary feed is used to produce 1 tonne of fish in the improved-extensive and semi-intensive systems equates to a total use of around of 80 000 tonnes of supplementary feeds, the bulk of which consists of bran and mustard oilseed cake. It is estimated that a further 20 000 tonnes of supplementary feeds are used for the production of seed, such that the total feed use by extensive and semi-intensive farmers is around 100 000 tonnes or 44 percent of the total aquafeed use in the country. By comparison, the semi-intensive and intensive farmers who produce mainly pangas and other high value products use 56 of the feed to produce 11 percent of total aquaculture production.

8. PROBLEMS AND CONSTRAINTS OF FEED AND FERTILIZER USE IN AQUACULTURE

- Many of the poor and marginal farmers have a limited understanding of the feed and nutrient requirements of the animals they are producing. They mainly practice extensive aquaculture with limited and irregular use of feeds and fertilizers and production levels are low.
- Semi-intensive and intensive farmers are reliant on poor quality feeds irrespective of whether the feed is made by the formal aquafeed industry or by small-scale feed mills. Similarly, this is also largely a consequence of their limited knowledge about the nutritional requirements of the culture species, the proximate composition of the ingredients and price. Manufacturers often use cheaper ingredients of inferior quality, resulting in poor feed quality and lower than expected yields. Facilities to test the composition of ingredients and composite mixed feeds are not readily available to farmers, who have to bear the consequences and the costs.
- The aquafeed industry is unregulated and feed quality is not guaranteed. Hence there is an urgent need to finalise and implement policy for aquafeed regulation and a need to build the requisite capacity and facilities to manufacture high quality aquafeeds.
- The seasonally limited availability and supply of aquafeed ingredients is problematic. Competition for these commodities by other users, e.g. the poultry feed industry is high, which result in higher prices. Many storage facilities are antiquated and inadequately resourced to store the ingredients in an appropriate and safe manner such that they are readily available throughout the year.

9. RESOURCE AVAILABILITY AND THE EXPANSION OF THE AQUACULTURE INDUSTRY

Fish production in Bangladesh can be increased through further improvements in the improved-extensive and semi-intensive culture systems for carps, prawn and shrimp, in particular by increasing farmer awareness in the use of feeds and fertilizers. Access to farm inputs by poor and marginal farmers has to be improved in order to increae rural fish production.

The rapidly growing feed manufacturing sector must be regulated with respect to feed quality, such that famers are in a position to purchase quality feeds. This would result overall in higher production levels. Moreover, there is a need for the formal aquafeed industry to become more pro-active with respect to the supply of and quality of ingredients. The demand for feed has to be estimated by the industry on a regular basis so that the demand can be met at a reasonable cost.

10. RECOMMENDATIONS

The recent advances in aquaculture production have given rise to several new constraints. These must now be addressed in order for the industry to expand in Bangladesh. The following recommendations may be useful for the sustainable development of the aquaculture sector:

- The degree of cooperation between government and university laboratories to provide support to the aquafeed industry to manufacture high quality feeds and to provide information on the nutritional requirements of fish must be improved.
- Information on appropriate storage methods and modern fishmeal manufacturing technology needs to be disseminated.
- Extension services must provide a greater degree of support to farmers such that they are able to manufacture better farm-made feeds.
- Extension services must provide appropriate information to farmers for improved fertilization schedules to enhance natural pond productivity.
- Extension services must promote the effective use of inorganic fertilizers in fish culture to increase natural pond productivity.
- Intensive producers must be educated in the judicious use of aquafeeds and expansion of their activities in a controlled manner.
- Extension services must educate poor and marginal farmers (carp farmers) throughout the country to improve their production through regular use of nutrients and feeds.

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APPENDIX

A.1. Family, common English and scientific names of major aquaculture species in Bangladesh

Major group	Family	Common English name	Scientific name
Major carps	Cyprinidae	Rohu	*Labeo rohita*
		Catla	*Catla catla*
		Mrigal	*Cirrhinus cirrhosus*
Exotic carps	Cyprinidae	Silver carp	*Hypophthalmichthys molitrix*
		Common carp	*Cyprinus carpio*
		Common/mirror carp	*Cyprinus carpio*
		Grass carp	*Ctenopharyngodon idella*
		Java barb	*Barbonymus gonionotus*
Other carps	Cyprinidae	Kuria labeo	*Labeo gonius*
		Orange-fin labeo	*Labeo calbasu*
		Olive barb	*Puntius sarana*
Snakeheads	Channidae	Snakehead murrel	*Channa striata*
		Great snakehead	*Channa marulius*
		Spotted snakehead	*Channa punctata*
Catfishes	Bagridae	Rita	*Rita rita*
		Long-whiskered catfish	*Sperata aor*
		Giant river-catfish	*Sperata seenghala*
	Siluridae	Wallago	*Wallago attu*
	Pangasiidae	Yellowtail catfish	*Pangasius pangasius*
		Sutchi catfish	*Pangasius hypophthalmus*
	Schilbeidae	Silond catfish	*Silonia silondia*
		Catfish	*Eutropiichthys vacha*
	Heteropneustidae	Stinging catfish	*Heteropneustes fossilis*
	Clariidae	Walking catfish	*Clarias batrachus*
		North African catfish	*Clarias gariepinus*
Climbing perch	Anabantidae	Climbing perch	*Anabas testudineus*
Other fishes	Notopteridae	Clown knifefish	*Notopterus chitala*
		Bronze featherback	*N. notopterus*
	Percidae	Nile tilapia	*Oreochromis niloticus*
		Mozambique tilapia	*O. mossambicus*
Shrimps & prawns	Penaeidae	Black tiger shrimp	*Penaeus monodon*
		White shrimp	*Penaeus indicus*
		Brown tiger shrimp	*Penaeus semisulcatus*
		Brown shrimp	*Penaeus brevicornis*
		Brown shrimp	*Metapenaeus monoceros*
		Shrimp	*Parapenaeopsis sculptilis*
	Palaemonidae	Giant freshwater prawn	*Macrobrachium rosenbergii*
		Monsoon river prawn	*Macrobrachium malcolmsoni*

Source: Hasan (1990); FishBase (05/2007) (http://www.fishbase.org/search.php)

B.1. Amino acid composition of feed ingredients used in Bangladesh (percent dry matter)

Amino acids	Fishmeal	Fish silage	Bonemeal	Silkworm pupae	Poultry offal	Soybean meal	Sesame meal	Mustard oilcake	Linseed meal	Cotton seed	Leucaena meal	Water hyacinth	Duckweed meal	Rice bran	Wheat bran
Threoonine	3.13	2.52	5.37	2.29	2.64	1.63	1.21	1.46	1.24	1.21	1.21	1.08	0.70	0.47	0.49
Cystine	0.48	0.44	0.88	0.73	0.69	0.28	0.32	0.70	0.37	0.39	0.17	0.10	0.12	0.14	0.18
Valine	3.16	2.53	7.90	3.01	3.85	2.10	1.27	1.47	1.75	1.56	1.49	1.19	0.76	0.59	0.62
Methionine	1.95	1.75	1.20	1.22	1.04	0.54	1.37	0.32	0.58	-	0.58	0.17	0.09	0.23	-
Isoleucine	2.65	2.13	0.85	2.66	3.47	1.82	0.92	1.34	1.41	1.15	1.12	0.95	0.50	0.37	0.42
Leucine	4.96	4.46	10.34	4.19	4.92	3.37	1.79	2.32	2.43	1.92	2.22	1.75	1.10	0.72	0.89
Tyrosine	2.23	1.92	2.43	3.49	2.42	1.29	0.56	0.73	0.64	0.64	0.87	0.68	0.39	0.19	0.29
Phenylalanine	2.54	2.16	6.84	1.89	3.13	2.22	2.11	1.38	1.53	1.51	1.57	1.19	0.71	0.47	0.61
Histidine	0.65	0.53	4.95	2.30	1.56	1.24	0.63	0.72	0.75	0.65	0.42	0.46	0.26	0.30	0.46
Lysine	4.85	4.12	7.78	4.56	3.95	3.01	1.27	1.96	1.18	1.27	1.33	0.98	0.93	0.49	0.64
Arginine	3.64	3.10	3.96	3.13	3.95	3.48	2.91	1.81	2.23	2.90	1.48	1.02	1.81	0.68	0.89

Source: Hossain (1996)

Analysis of feeds and fertilizers for sustainable aquaculture development in China

M. Weimin
Freshwater Fisheries Research Centre
9 East Shanshui Road, Binhu District, Wuxi 214081
China
L. Mengqing
Yellow Sea Fisheries Research Institute
PO Box 266071, 106 Nanjing Road, Qingdao
China

Weimin, M. and Mengqing, L. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in China. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 141–190.

SUMMARY

Over the past quarter-century, aquaculture in China has recorded an annual average increase in production of 13.5 percent. In 2004, total production was 32.09 million tonnes. The rapid development of the aquaculture sector has significantly stimulated the development of the aquafeed industry in China. In recent years commercially manufactured feed production has been increasing at a rate of about 20 percent annually. Developments in and expansion of the aquafeed industry has further spurred the development of aquaculture in the country. Recent trends in the intensification of aquaculture and species diversification have had significant impacts on the production and use of feeds and fertilizers, which may negatively impact on the sustainable development of the sector in China. For example, in 2004 average yields in freshwater pond culture reached 5.5 tonnes/ha, which is a 60.4 percent over average yields attained in 1994. Similarly, the number of freshwater species groups included in the national production statistics increased from 11 in 1995 to 40 in 2004.

This review summarizes the development of the aquaculture industry in China and its contribution to animal protein food supply, income and employment generation, export earnings and the national economy. Aquaculture currently supplies about 30 percent of animal food to the Chinese people. At the same time, the industry provides some 4.5 million full time and 3–4 million part-time jobs for rural communities. In 2004, the average annual income of aquaculture labour (US$1 100) was nearly double that of the income in agriculture. Aquaculture systems and practices, in particular on-farm feed management strategies and pond management techniques have been introduced to improve feed and fertilizer utilization to enhance fish and shellfish production. Research on the nutritional requirements of culture species and the development of technologies for improved pond and water quality management, the use of water quality promoting agents and improved methods of feed preparation, formulation and presentation have been the major driving forces of the sector in the recent past.

An overview is provided of the various feed ingredients, feeds and fertilizers commonly used in aquaculture in China with particular emphasis on how they are used. It was estimated that about 70 percent of the total aquafeed produced in China is used in freshwater pond culture of grass carp, common carp, crucian carp and tilapia. A significant proportion of pond aquaculture in China is dependent on farm-made feeds containing feedstuffs such as rice bran, rapeseed meal, peanut meal, soybean meal, silkworm pupae either singly or in combination with organic and inorganic fertilizers. Shrimp culture in China is mainly an earthen pond based activity using good quality industrially manufactured compounded feed with FCRs that vary between 1.2 and 1.6:1. In comparison to freshwater fish production, the output from mariculture remains very low. Marine fish culture employs net-cages, land-based tank and earthen pond systems. Marine fish cage culture largely depends on trash fish, while extruded feeds in combination with farm-made feeds are used in land-based tank culture systems and earthen ponds. It was estimated that about 4 million tonnes of trash fish are directly used as aquafeeds annually.

The development of the aquafeed industries were reviewed with emphasis on carps, tilapia, bream, eel and shrimp. In 2004, approximately 8 million tonnes of compound aquafeeds were produced and this accounted for about 8.6 percent of total animal feed production in China. Attention was also given to recent developments in aquafeed quality assurance and control standards.

The major challenges facing the aquaculture industry and its sustainable development in China are availability of and accessibility to aquaculture feed ingredients especially fishmeal, availability of organic fertilizers, economic and social constraints with respect to feed resource use, preparation of farm-made feeds, feed application and use of commercially manufactured pellet feeds by small to medium-scale farmers. In addition and as important are social and environmental impacts caused by improper use of

commercially manufactured aquafeeds. Globally, China is one the largest importers of soybean products and fishmeal. Between 2000 and 2004 soybean and fishmeal imports increased by nearly 100 percent, in comparison with an increase of only 60 percent during the preceding decade. The rapid expansion of the aquafeed industry is the principal reason for this increase in import volumes. If this trend were to continue it would seriously impact on the supply-demand balance of these two feed ingredients in world trade.

The advantages and disadvantages of the increasing dependence on commercial feeds are considered. While there are some distinct advantages the disadvantages are many and these could have serious environmental impacts and negative economic consequences for small to medium-scale farms.

Strategies and approaches to use feed ingredients, feeds and fertilizer more efficiently for sustainable aquaculture development in China are suggested. These include, among others, improving feed formulations and manufacturing technology, sourcing new and alternative feed ingredients, the important role of science and technology to improve nutrient absorption of presently used feedstuffs, particularly protein sources and improving on-farm feed management. Recommendations are provided for the implementation of these strategies, which include government incentives to promote resource efficient aquaculture systems and practices, regulating measures such as tightening the control over aquaculture effluent discharge, discouraging the inefficient use of feed ingredients and stronger support for systematic aquaculture feed and feeding related research and development activities.

1. GENERAL OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

1.1 History and present status of aquaculture in China

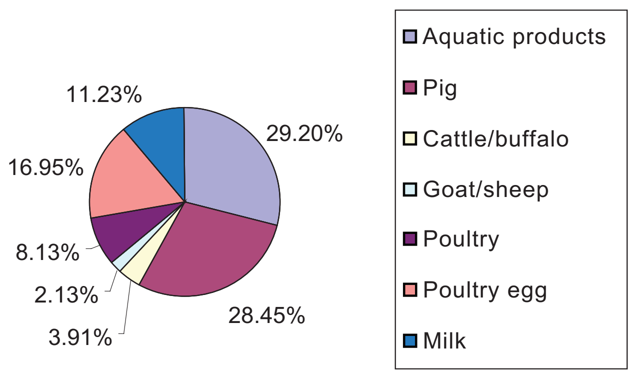
The earliest recorded history of aquaculture in China dates back over 2 500 years to the "The Treatise on Pisciculture"- the first monograph on aquaculture in the world written by Fan Li. Earliest aquaculture practices started with pond culture of common carp and continued for about 1 500 years when this practice was forbidden during the Tang Dynasty some 1 200 years ago. This led to the introduction of integrated polyculture, using four Chinese carps. Extensive fish culture practices in open-waters were initiated during more or less the same period. The traditional aquaculture practices remained virtually unchanged until the 1970s.

The development of aquaculture as a modern industry in China started in the early 1980s, after implementation of economic reforms and the "open-door" policy. The development of the sector in the last quarter of a century was characterised by rapid expansions in scope, production, technological advances, particularly with respect to seed production, diversification of species and farming systems and advances in management skills and systems. More recently there has been a trend towards greater intensification of culture systems and the introduction of new species. These factors have been the major driving forces for developments in feed technology and feeding practices. Feed and feeding have become the most important factors influencing the performance of different aquaculture practices and the development of the sector as a whole.

Within the last 20 years aquaculture has become the most important component of the fisheries sector in China. In 1988 fisheries production exceeded 10 million tonnes and for the first time aquaculture contributed over 50 percent of the total. Since 1993, the contribution by aquaculture has reached 60 percent. In 2003, aquaculture production amounted to some 30.27 million tonnes and this makes a significant contribution to the total animal protein supply, income generation of rural households and the national economy. China currently accounts for about 70 percent of global aquaculture production.

Presently, the fisheries sector provides about 30 percent of animal protein consumed in China (Figure 1), although fish consumption varies regionally. On a per capita basis people in the southeastern part of the country consume the largest quantities of aquatic products, while in the northwest consumption is much lower. By 2003, aquaculture contributed 65.5 percent to total fisheries production, provides about 20 percent of total animal food supply to the peoples of China and per capita availability of aquatic products increased from <10 kg/caput in 1980 to its present level of 37 kg/year.

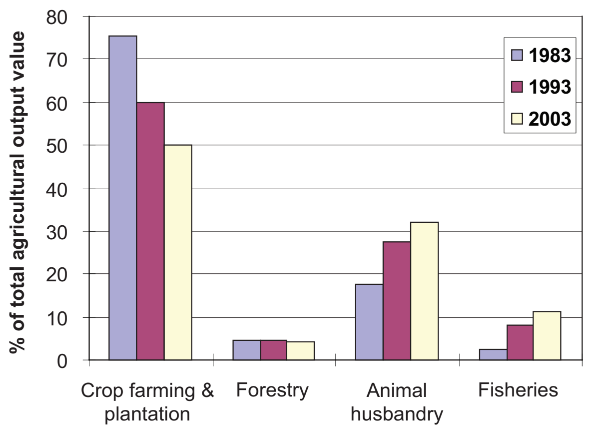
FIGURE 1
Relative contribution to total animal food supply by various sectors in 2004



Source: MOA (2004)

Aquaculture also makes a significant contribution to the national economy. In 2004, the value of the Chinese fisheries sector amounted to about US$46.3 billion, to which aquaculture contributed 72.4 percent. In 2003, fisheries (aquaculture and capture fisheries) comprised 11.2 percent of the total national agricultural output, of which 70.3 percent was from aquaculture and in the same year fisheries comprised 2.8 percent of GDP. As shown in Figure 2, the share of fisheries to the total value of agricultural output has increased significantly in the past 20 years.

FIGURE 2
Proportional changes in the value of agricultural outputs, 1983–2003



Source: MOA (1984, 1994, 2004)

Aquatic products have become the most important agricultural exports of China. In 2004, the total value of exported fisheries products reached US$5.49 billion with a trade surplus of US$3.01 billion. The export value of aquatic products accounted for 23.5 percent of the total agricultural export value (US$23.39 billion with a foreign trade deficit of US$4.6 billion). Although aquatic products only accounted for 0.93 percent of total national exports in 2004, the trade surplus accounted for 9.41 percent of the total national foreign trade surplus (US$32 billion). Currently the bulk of exported fisheries products are aquaculture products.

Aquaculture contributes significantly to employment, livelihoods and income of rural people in China. In 2004, the fisheries industry employed approximately 13.02 million people, of which 7.12 million were full time workers (4.49 million in aquaculture). In 2004, the average income for fisheries workers reached US$1100/year, which is about 45 percent higher than in the agricultural sector as a whole.

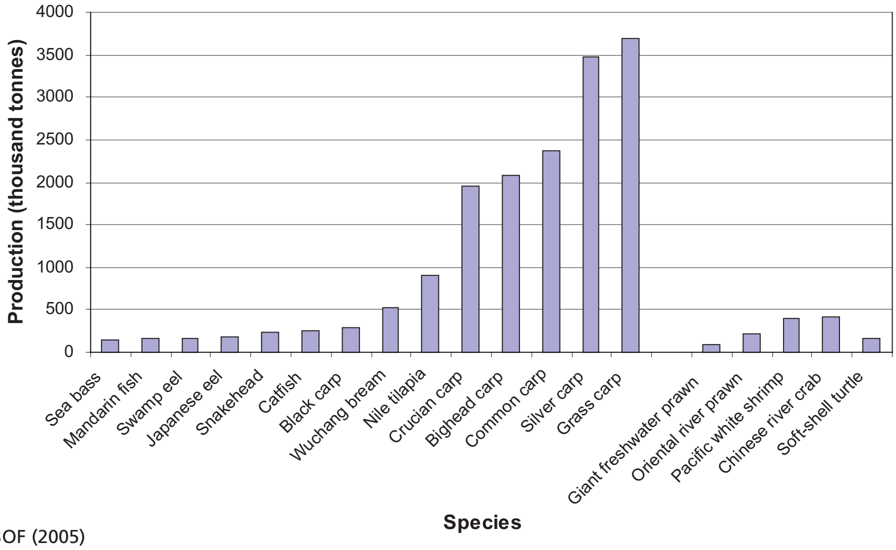
1.2 Aquaculture production by species and practices in China

1.2.1 Production by species

Since the middle of the 1990s, changes in consumer demands and the pursuit by farmers to increase returns have stimulated the strong diversification of species in all aquaculture systems and practices. Currently, the number of species cultured in freshwater, brackish-water and marine environments exceeds 100. In 2004, about 80 different species were included in the national statistical database of aquaculture production. Production by volume and value of the major aquatic species in inland water bodies are shown respectively in Figures 3 and 4. In 2004, grass carp, silver carp, common carp, bighead and crucian carp accounted for 71.7 percent of the total inland waters aquaculture production in China. Of these species, grass carp has become the most important. Although different carp species still contribute the largest share, the contribution by other species has become significant in relation to production by value. This is mainly due to the higher market value of species such as crab, shrimps, freshwater prawns and eels.

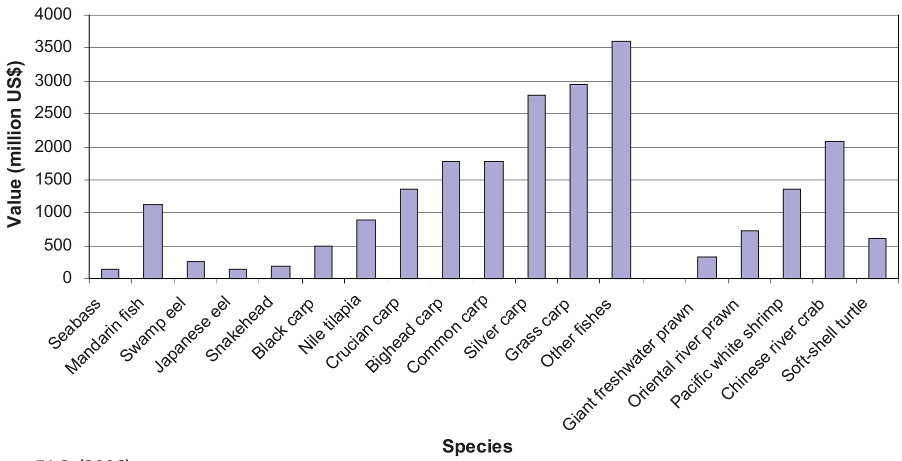
Figure 4 shows the production of the major finfish and crustacean species in brackish-water and marine environments. In 2004, production by volume in these two environments was dominated by shrimp that account for about 37.9 percent of total production. Pacific white shrimp (*Litopenaeus vannamei*) has become the single most important culture species. The value of the major marine and brackish-water finfish and crustaceans produced in 2004 is shown in Figure 6. In terms of value this sector is dominated by shrimp and prawns.

FIGURE 3
Production of major aquaculture species in inland water in China, 2004



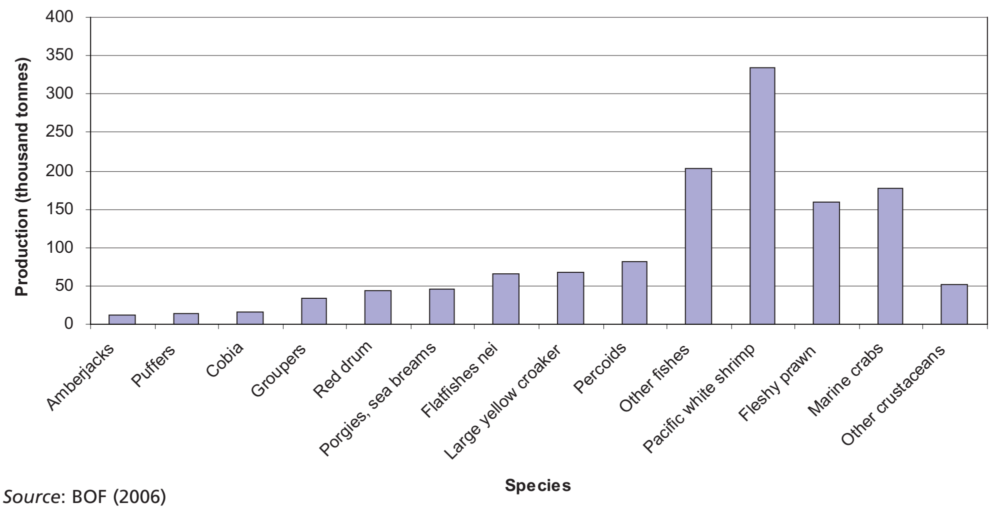
Source: BOF (2005)

FIGURE 4
Production value of major aquaculture species in inland water in China, 2004



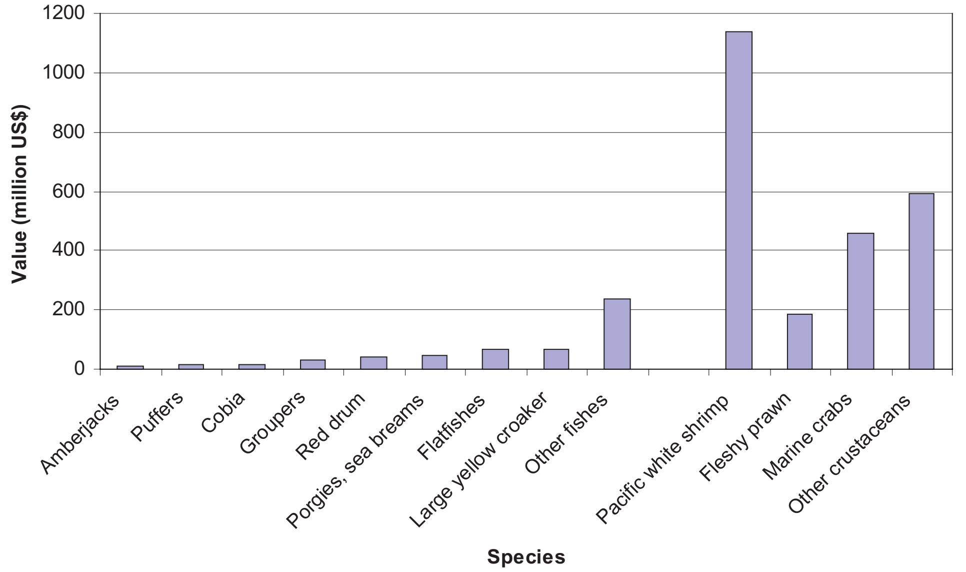
Source: FAO (2006)

FIGURE 5
Production of major marine and brackish-water fish and crustaceans in China, 2004



Source: BOF (2006)

FIGURE 6
Production value of major marine and brackish-water fish and crustacean in China, 2004



Source: FAO (2006)

1.2.2 Production by systems and practices

Due to the organizational structure of fisheries and aquaculture statistics in China, it is not possible to provide a precise account of production by systems, although it is possible to undertake an approximate assessment of production of the different species under major culture practices. However, there is no doubt that semi-intensive pond polyculture of carp contributes the major share of inland aquaculture production. The estimated production from the major inland aquaculture practices are presented in Table 1 and Table 2 summarizes the production of marine and brackish-water species by systems. Mollusc monoculture and seaweed culture is not considered in this review.

TABLE 1
Estimated production from major inland aquaculture practices in China, 2004

Major practices	**Estimated production (million tonnes)**
Semi-intensive polyculture of carps in pond	9–10
Extensive polyculture of carps in natural water bodies	3–4
Intensive monoculture of common carp, crucian carp and tilapia	2–3
Semi-intensive/intensive monoculture of freshwater prawns and crabs in ponds	1.0
Extensive polyculture/monoculture of fish/prawn/crab in paddy fields	1.0
Semi-intensive pen polyculture of carps	0.50
Intensive cage monoculture of high valued species	0.50
Highly intensive culture of eels, soft-shelled turtle and puffer fish in indoor re-circulating systems	0.10

Source: calculated from BOF (2005)

TABLE 2
Estimated production from different marine/brackish aquaculture practices in China, 2004

Major practices	**Estimated production (tonnes)**
Semi-intensive/intensive monoculture of shrimp in ponds	530 000
Extensive polyculture of crab/shrimp/mollusk in ponds	190 000
Extensive culture of seabass and other species in ponds and pens	100 000
Intensive monoculture of grouper/yellow croaker and other species in cages	150 000
Semi-intensive/intensive culture of porgies/red drum/cobia/amberjack in ponds	100 000
Intensive monoculture of high valued fish in indoor re-circulating systems	80 000

Source: calculated from BOF (2005)

1.3 Aquaculture systems and practices in China

1.3.1 Aquaculture systems

The classification of aquaculture systems is usually based on the level of intensity, although the culture environment and the species composition are also often taken into consideration. Considering these aspects, the major aquaculture systems employed in China are listed in Tables 3 and 4.

1.3.2 Aquaculture practices

An important indicator of the rapid development of aquaculture in China is the rate of diversification in aquaculture practices in the past two decades. With over 100 different species that are farmed in a wide variety of environments throughout China it is very difficult to estimate and describe the various practices applied by farmers. Hence only some of the more important aquaculture practices and their major features are listed in Tables 5 and 6.

Extensive culture of carps in small lakes and reservoirs

This practice started in the 1960s and is the most extensive form of polyculture practiced in the country (Figure 7). In these water bodies the fish are entirely dependent on natural productivity. Stocking of artificially produced seed is the only material input. Bighead and silver carp are the major species and common, crucian and grass carp, wuchang

TABLE 3
Inland aquaculture systems and species in China, 2004

Culture system	Major species
Extensive polyculture in lakes/reservoirs	Wuchang bream, crucian carp, bighead carp, common carp, silver carp, grass carp, Chinese river crab
Semi-intensive polyculture in ponds	Grass carp, common carp, wuchang bream, tilapia, crucian carp, bighead carp, silver carp, largemouth bass, Mandarin fish, black carp, tilapia, giant freshwater prawn, oriental river prawn, Chinese river crab, soft-shell turtle
Intensive monoculture in ponds	Largemouth bass, Mandarin fish, Japanese eel, snakehead, catfish, tilapia, crucian carp, common carp, giant freshwater prawn, oriental river prawn, Pacific white shrimp, Chinese river crab, soft-shell turtle
Semi-intensive polyculture in cages	Wuchang bream, grass carp, tilapia
Intensive monoculture in cages	Largemouth bass, Mandarin fish, catfish, tilapia, common carp
Semi-intensive polyculture in pens	Grass carp, wuchang bream, black carp, crucian carp, bighead carp, common carp, silver carp, Mandarin fish, Chinese river crab
Extensive integrated rice-fish farming	Swamp eel, catfish, tilapia, crucian carp, bighead carp, common carp, silver carp, grass carp, oriental river prawn, Chinese river crab
Highly intensive indoor re-circulating systems	Japanese eel, soft-shell turtle, puffer fish, sturgeon

TABLE 4
Brackish-water and marine aquaculture systems and species in China, 2004

Culture system	Major species
Semi-intensive polyculture in ponds	Shrimp with molluscs, marine crabs, finfish and seaweed
Intensive monoculture in ponds	Amberjacks, red drum, black porgy, red sea breams, percoids, Pacific white shrimp, fleshy prawn, tiger prawn
Extensive culture in ponds	Percoids, mullet, crab
Intensive monoculture in cages	Amberjacks, cobia, groupers, red drum, black porgies, red sea breams, flatfishes, large yellow croaker, seabass
Extensive polyculture in pens/coves	Mullet, percoids, marine crabs
Intensive monoculture indoor re-circulating systems	Flounder, turbot, red drum, red sea breams

bream and Chinese river crab are secondary species and stocking is undertaken according to well defined schedules with respect to species composition, size and density. Depending on the size and productivity of the waterbody, stocking densities range from 150–3000 seed/ha. Care is taken to prevent the escape of fish by blocking the outlet and inlet water courses with fencing material and production ranges from 150–750 kg/ha/year without any artificial feeding and fertilization, although smaller irrigation reservoirs may be fertilized.

FIGURE 7
Harvesting of carp with combined fishing gears in Xinanjiang Reservoir, Zhejiang province

COURTESY OF FANG XIUZHEN

Semi-intensive and intensive culture of carp in freshwater ponds

Pond culture is the most traditional aquaculture practice and also the most important in terms of total fish production in China. Carp species are still used as the primary species in semi-intensive pond polyculture together with tilapia (mainly *O. niloticus*), crab, prawns and some carnivorous species such as Mandarin fish and largemouth bass as secondary species. A large variety of feeds are used, including natural feeds (aquatic weeds/terrestrial grass, benthic animals, abattoir by-products and silkworm pupae) and commercial pellets. Ponds are fertilized only during preparation and stocking density, size of seed and species composition is dependent on the production target.

Semi-intensive and intensive culture of carp in pen

Pen culture is a relative new practice that was introduced into China in the early 1980s to increase fish production in freshwater lakes. Polyculture of different carp species under semi-intensive conditions is the most common practice. Herbivorous species (grass carp and wuchang bream) are usually stocked as the primary species, while silver, bighead, common and crucian carps are used as secondary species. Commercial feeds such as soybean and rapeseed cake, pellet feeds and natural feed such as aquatic weeds/terrestrial grasses/vegetables and freshwater molluscs are commonly used. Production ranges between 10–15 tonnes/ha/year although levels of 37.5 tonnes/ha have been attained under experimental conditions.

Extensive culture of carps, tilapia and catfish in paddy field

This is a traditional aquaculture practice and is particularly popular in southern China (Figure 8). Peripheral and central crossing trenches are constructed in the paddy to maintain the required minimum water depth throughout the culture period. Fish are stocked before or after rice seedling are transplanted at very low densities. Because of the short culture period, farmers normally stock large juveniles. Supplementary feeds are applied occasionally and the application of pesticides is well managed to ensure the biosafety of the fish. Production ranges between 450–750 kg/ha/year, depending on input levels and management.

FIGURE 8
Extensive culture of fish/prawn/crab in a paddy field, Dongping, Shangdong province

Intensive monoculture of tilapia, common and crucian carp in ponds

Intensive monoculture of tilapia, common and crucian carp is a more recent practice in China. It is characterized by high stocking densities and complete dependence on pellet feeds. Production ranges between

FIGURE 9
Intensive monoculture of tilapia in cages in a reservoir, Hepu County, Guangxi Autonomous region

12–22.5 tonnes/ha/year. Tilapias are cultured mainly in southern China, while common and crucian carp are more generally produced in central and northern China.

Intensive monoculture of common carp and tilapia in cages
Intensive, cage monoculture of common carp is more popular in northern China, while intensive cage culture of tilapia is mainly practiced in southern China (Figure 9). The fish are entirely dependent on pellets and for common carp and both floating and submerged cages are used. Production of common carp in small cages can reach 200–300 kg/m^3/cycle. Tilapia are raised only in floating cages and production ranges from 50–100 kg/m^3/cycle.

Extensive culture of freshwater prawns and crabs in paddy fields
Extensive culture of freshwater prawns and crabs in paddy fields is a recent development, particularly in central and southern China. Production is basically dependent on natural food in the paddy fields. Supplementary feeds (locally available grain by-products and natural feeds) are sometimes applied. Average production is 7.5 tonnes of rice and 300–450 kg of prawns or crabs per hectare per season. Silver and/or bighead carp are occasionally also stocked into the ponds at low densities.

Semi-intensive and intensive monoculture of freshwater prawns in ponds
Semi-intensive and intensive monoculture of freshwater prawns in ponds is also a relatively new practice in China. It started with *Macrobrachium rosenbergii* and now also includes *M. nipponense* and *Litopenaeus vannamei*. *L. vannamei* is currently the most important crustacean produced in freshwater. The prawns or shrimp are fed on pellets and organic fertilizer is used to enhance natural productivity during the initial culture stages. Production levels vary by species from 1.5–3.0 tonnes/ha/cycle for *M. nipponense,* 6.0–7.5 tonnes for *L. vannamei* and 3.0–4.5 tonnes for *M. rosenbergii.*

Intensive monoculture of eels in ponds
Pond aquaculture is the most common farming practice for Japanese and European eels in China, particularly in Fujian and Guangdong provinces. Production is based on formulated feeds and organic fertilizer is only applied during pond preparation to enhance natural food production during the initial stages. Average production is around 15 tonnes/ha/cycle.

Semi-intensive and intensive culture of shrimp in brackish-water ponds
Semi-intensive and intensive brackish-water pond culture is the major culture practice for *L. vannamei*, *Penaeus monodon*, *Penaeus chinensis* and other marine shrimp species. It is mainly practiced in coastal areas and production is mainly based on use of pellet feeds. Organic fertilizer is used only in semi-intensive culture practices. Production in semi-intensive farming ranges from 1.5–2.5 tonnes/ha/cycle for *P. monodon, P. chinensis* and *P. japonicus* and between 4.5–9.0 tonnes/ha/cycle for *L. vannamei*. Intensive farming of shrimp in brackish-water ponds is normally restricted to *L. vannamei,* with production levels of 15–30 tonnes/ha/cycle.

Intensive monoculture of finfish in marine cages
Intensive, cage monoculture of large yellow croaker, grouper, cobia (Figure 10) and red drum is a relatively recent development. The most commonly used feed is trash fish, although formulated feeds have now also been developed and used for some species.

FIGURE 10
Intensive monoculture of cobia in marine cages, Shandong province

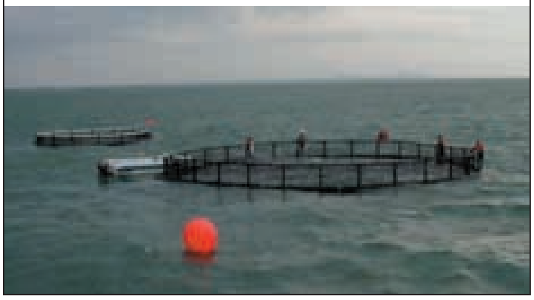


FIGURE 11
Intensive culture of marine fish in indoor running water system, Shandong province

Production varies according to species and ranges from 15–30 kg/m^3/cycle.

Intensive culture of marine finfish in indoor flow-through or re-circulating systems
The use of indoor, marine re-circulating or flow-through systems for intensive monoculture of flounder, turbot, Japanese/European eel and puffer fish is also a recent initiative (Figure 11). Only formulated feeds are used in these systems and production varies by species from 3–10 kg/m^3/cycle.

TABLE 5
Summary of major inland aquaculture practices in China, 2004

Culture environment	Polyculture/ monoculture	Major species	Intensity level	Food/feed type	Yield per cycle*
Lake/reservoir	Polyculture	Carps, Chinese river crab	Extensive	Natural food	150–750 kg/ha
Pond	Polyculture	Carps, tilapia, soft-shelled turtle, Chinese river crab, Mandarin fish	Semi-intensive	Natural food, commercial feed	7.5–15.0 tonnes/ha
	Monoculture	Common & crucian carp	Intensive	Commercial feed	15.0–22.5 tonnes/ha
	Monoculture	Tilapia	Intensive	Commercial feed	15–20 tonnes/ha
	Monoculture	Japanese/European eel	Intensive	Commercial feed	15 tonnes/ha
	Monoculture	Giant freshwater prawn	Intensive	Commercial feed	3.0–4.5 tonnes/ha
	Monoculture	Pacific white shrimp	Intensive	Commercial feed	6–12 tonnes/ha
	Monoculture	Oriental river prawn	Semi-intensive	Natural food and commercial feed	1.5–3.0 tonnes/ha
	Monoculture	Chinese river crab	Semi-intensive	Natural food and commercial feed	1.5–3.0 tonnes/ha
Cage in river/ lake/reservoir	Polyculture	Grass carp, Wuchang bream	Semi-intensive	Natural food and commercial feed	30–60 kg/m^3
	Monoculture	Tilapia	Intensive	Commercial feed	80–100 kg/m^3
	Monoculture	Common carp	Intensive	Commercial feed	100–200 kg/m^3
	Monoculture	Catfish	Intensive	Trash fish and commercial feed	60–100 kg/m^3
	Monoculture	Mandarin fish, largemouth bass	Semi-intensive	Live fish/trash fish	10–20 kg/m^3
Pen in lake/ reservoir	Polyculture	Carps	Extensive/ semi-intensive	Natural food and commercial feed	10–20 tonnes/ha
	Polyculture	Chinese river crab with carps	Semi-intensive	Natural food and commercial feed	Crab 6–9 tonnes/ha
Rice paddy	Polyculture	Carps, catfish, prawn	Extensive	Natural food and supplementary feed	450–750 kg/ha
	Monoculture	Chinese river crab, swamp eel	Extensive	Natural food and supplementary feed	225–450 kg/ha
Indoor re-circulating	Monoculture	Japanese eel/European eel	Intensive	Commercial feed	10 kg/m^3
	Monoculture	Soft-shelled turtle	Intensive	Natural food and commercial feed	5–10 kg/m^3

*Duration of a production cycle ranges from 6 months to 3 years depending upon the species and the region where aquaculture is practised. The duration of production cycle of prawn and shrimp is usually 6 months, 1.5–2.0 years for most carp species, while it is 2–3 for eel.

TABLE 6
Summary of major marine/brackish aquaculture practices in China, 2004

Culture environment	Polyculture/ monoculture	Major species	Intensity level	Food/feed type	Yield per cycle
Brackish-water ponds	Polyculture	Shrimp, mullet, tilapia, crab	Semi-intensive	Commercial feeds and natural food	4–6 tonnes/ha
	Monoculture	Shrimp	Intensive	Commercial feeds	15–20 tonnes/ha
	Monoculture	Tilapia/black porgy	Intensive/semi-intensive	Commercial feeds	15.0–22.5 tonnes/ha
	Monoculture	Shrimp	Semi-intensive	Commercial feeds and natural food	1.5–3.0 tonnes/ha
Marine cages	Monoculture	Large yellow croaker/ grouper/tilapia/red sea bream/black porgy/ seabass	Intensive	Trash fish/ commercial feeds	15–30 kg/m^3
Indoor re-circulating	Monoculture	Flounder, trout	Highly intensive	Commercial feeds, moist pellet	10 kg/m^3

2. FERTILIZERS, FEED INGREDIENTS AND FEEDS

2.1 Feed Ingredients

Aquaculture is a development priority of the government and the industry is expected to make further advances in the 21st century. The availability of feed ingredients is one of the key factors that will impact on the future development of aquaculture in China. For this reason it is pivotal to assess the future availability of feed ingredients. The chemical composition, amino acid profile, mineral and vitamin content and the apparent nutrient and amino acid digestibility of selected feed ingredients of animal and plant origin by various aquatic species are presented in Tables 7 to 18.

2.1.1 Feed ingredients of animal origin

The major feed ingredients of animal origin in China are fishmeal, hydrolyzed poultry feather meal, squid meal, fish silage, meat by-product meals, poultry by-product meal, blood products, silkworm pupae meal and shrimp meal. Many of these ingredients, especially fishmeal, are imported and efforts are being made to partially replace imported feed ingredients with locally available material.

Fishmeal

Most of the locally produced fishmeal is produced from various clupeid species such as *Engraulis japanicus*, *Sardinella longiceps*, *Coilia ectenes*, and *Sardinops sagax melanosticta*. Occasionally fishmeal from other species is also available. Approximately 400 000 tonnes of fishmeal is produced in China, of which about 70–80 percent is used in aquafeeds. The escalating cost of fishmeal is now beginning to limit its use in aquafeeds. The average optimum inclusion levels of fishmeal in feeds for carnivores is 50.0 percent, omnivores/herbivores 25.0 percent, penaeid shrimps 25.0 percent and other crustaceans 20.0 percent.

Squid meal

Squid meal is a by-product of squid processing and is an important aquafeed ingredient, particularly for shrimp. Squid meal has growth promoting properties and is a good attractant. Studies have shown that squid contains some unidentified growth enhancing factor, which presently is simply referred to as the "squid factor". Growth of Pacific white shrimp (*Litopenaeus vannamei*) is enhanced by 2.5–20 percent when the diet is supplemented with squid meal. Squid meal is produced in China and is also imported. Reliable production statistics are not available.

Fish and other marine silage

Fish and other marine silages are liquid concentrates, manufactured from trash fish and by-products and wastes of fish processing. The crude protein content (on a dry matter basis) varies widely, although the amino acid profile is not significantly different from that of dried fish. The level of free amino acids in fish silage is high. Silage made from marine fish and crustaceans has chemo-attractant properties. In particular, shrimp silage has some feeding stimulatory properties for a variety of fish species. Fish silage may also contain unidentified growth enhancing factors.

Meat by-product meal
Meat by-products include abattoir wastes, or meat that has been confiscated and not fit for human consumption, scraps from the meat processing and canning industry, as well as processed livestock casualties. These products are reduced to either meat or meat and bone meal. The chemical composition of meat meal and meat and bone meal varies widely and depends on the quality and origin of the raw material and the rendering plant.

2.1.2 Feed ingredients of plant origin and single cell proteins
The main ingredients of plant origin that are used or have potential to be used in aquafeeds in China are cottonseed meal, rapeseed meal, soybean meal, peanut meal, sunflower meal, wheat and wheat by-products and rice by-products. Most are locally produced and the country is only partially dependent on imports.

Cotton seed meal
It is estimated that about 8–10 million tonnes of cottonseed is produced in China per annum (http://www.chinafeed.org.cn/cms/code/business/include/php/189909.htm). It is estimated that about 4–5 million tonnes of cottonseed meal is produced annually of which approximately 60 percent is used in aquafeeds.

Rape seed meal
The reported annual production of rapeseed meal is about 5 million tonnes and it is estimated that approximately 80 percent is used by the aquafeed industry.

Soybean meal
Soybean meal is the most important protein source in animal feeds. It is used for partial replacement of fishmeal in many aquafeeds and in some instances replaces fishmeal completely. It is commonly used because of its high protein content and global availability. Annual soybean meal production in China is around 15.50–17.55 million tonnes, the greater proportion of which is solvent extracted.

Peanut meal
Similarly, peanut meal is one of the most important protein sources in animal feeds and is also used as a partial or total replacement for fishmeal. About 14–15 million tonnes are produced annually, of which about 30–40 percent is used in aquafeeds and the remainder is used for livestock feed.

Wheat and wheat by-products
Available wheat by-products are wheat bran, wheat middlings, wheat germ and wheat gluten. About 100 million tonnes of wheat is produced annually in China.

Rice by-products
The most commonly used rice by-product in aquafeeds is the bran. It is used mainly as an energy source. Rice pollard is also used in aquafeeds, but to a lesser extent. Rice bran is most often used in diets for omnivorous and herbivorous fish. It is inexpensive and used mainly for species such as grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*) and Nile tilapia (*Oreochromis niloticus*).

There are several locally produced single cell protein sources that are used as aquafeed ingredients and these are brewer's yeast, molasses yeast and brewers grain.

2.2 Fertilizers

Inorganic and organic fertilizers are applied in extensive and semi-intensive pond systems to stimulate the growth of natural food, although the popularity of fertilizers use in aquaculture is declining. All fertilizers are locally produced.

Inorganic fertilizer

The most widely used inorganic fertilizers in aquaculture are mono-ammonium phosphate and di-ammonium phosphate as nitrogen and phosphorus sources, urea as nitrogen source and ammonium sulphate.

Organic fertilizer

The most widely used organic fertilizers in ponds are pig, chicken and duck manure, cow dung and green fodder.

2.3 Feeding practices in relation to farming systems and species

Grass, silver, common, bighead and crucian carp account for more than 70 percent of the total freshwater aquaculture production and of these, grass carp is the most important species. About 70 percent of aquafeeds produced annually in China is consumed by grass carp, common carp, crucian carp and tilapia.

Herbivorous fish.

The most common herbivorous aquaculture species in China are grass and silver carp. Under cage culture conditions silver carp and bighead carp are fed on compound feeds, consisting of mainly plant based ingredients with a 30–40 percent crude protein content. The commercial carp feed industry supplies pressed and extruded floating pellets and is well established in the major carp producing regions. The growout period for carp under cage culture conditions ranges from 6 months to 1 year in tropical regions and in temperate regions may range from 1–2 years.

Omnivorous fish

The most common omnivorous species produced in China are common carp, crucian carp and Nile tilapia. Omnivorous fish larvae are fed on microparticulate diets in combination with *Brachionus, Acartia* and *Pseudodiaptomus* nauplii. Tilapia are farmed in a multitude of systems and environments (ponds, cages, raceways and reservoirs, in freshwater and brackish water, under mono- and polyculture conditions and under extensive conditions with limited inputs and under semi-intensive and super-intensive stocking densities with high inputs, in static and in flow-through water and in recirculation systems using biofiltration). Under most of these conditions they are fed on compound feeds.

The main protein sources used in tilapia feeds are fishmeal, soybean meal, peanut, rapeseed and cottonseed meal as well as meat and bone meal, meat meal and feather meal. Main energy sources include animal and vegetable fats, corn, wheat and wheat by-products. Vitamins and minerals are included separately, or as combined premixes. The feeds are also supplemented with phosphate and limestone and other additives may include antioxidants and binders.

Carnivorous fish

The main carnivorous species are large yellow croaker, seabass, black rock fish, grouper, cobia, red sea bream, turbot, flounder, red drum, and puffer. Large yellow croaker, black rock fish, grouper, cobia and red sea bream are cultured in cages using mainly trash fish. Seabass, puffer and red drum are produced in ponds with commercial feeds, farm-made feeds and trash fish. Turbot and flounder are cultured indoors in flow-through or re-circulating systems with farm-made feed and commercial feeds. Carnivorous fish feeds usually contain high levels of fishmeal and moderately low level of plant ingredients (primarily soybean meal).

Crustaceans

Shrimp are farmed mainly in ponds under semi-intensive conditions using artificial feeds. Shrimp feeds normally include moderately high levels of fishmeal, soybean meal, peanut meal, shrimp meal and wheat meal.

TABLE 7

Chemical composition (percent dry matter) of major feed ingredients of animal origin

Ingredients	Dry matter	Crude protein	Crude lipid	Ash	Crude fibre	NFE	Ca	P
Fishmeal								
Anchovy	92.0	68.2	9.3	16.9	-	5.6	-	-
Estuarine tapertail anchovy	93.1	54.9	2.4	11.3	0.2	1.9	-	-
Polack	94.0	55.1	12.8	26.7	0.8	4.6	-	-
Sardine	93.0	63.4	9.8	15.3	0.3	9.6	-	-
Sealed sardine	93.9	62.9	8.3	14.8	0.2	3.1	-	-
Mixed fish	92.6	58.3	10.0	22.5	0.6	1.2	-	-
Poultry feather meal	92.0	84.0	2.5	2.8	1.5	0.6	0.4	0.70
Squid meal	8.0–13.0	40.0–45.0	16.0–21.0	5.0–10.0	-	-	-	-
Fish silage	24.9	58.3	16.0	14.7	3.6	28.9		
Meat meal	94.6	54.0	8.8	27.5	2.4	-	8.0	3.80
Meat and bone meal	94.0	46.0	10.0	35	2.5	-	10.7	5.40
Blood meal	90.0	80.0	1.0	4.5	1.0	-	0.3	0.25
Silkworm pupae meal (full-fat)	88.9	55.1	23.2	3.8	5.5	6.4	-	-
Silkworm pupae meal (de-oiled)	91.9	72.8	2.0	5.6	6.2	7.3	-	-
Shrimp meal	92.5	37.2	1.3	38.2	21.4	-	15.0	2.20
Shrimp head meal	96.8	58.2	8.9	22.6	11.9	-	-	-
Shrimp shell meal	96.0	45.9	0.4	31.7	27.2	-	11.1	3.60

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

TABLE 8

Amino acid profile (percent dry matter) of major feed ingredients of animal origin

Amino acids	Fishmeal of different origin						Poultry feather meal	Squid meal	Fish silage	Meat meal	Meat & bone meal	Blood meal*
	Anchovy (true)	Tapertail anchovy	Polack	Sardine	Sealed sardine	Mixed fishmeal						
Arginine	3.88	6.6	6.6	6.6	5.3	5.4	5.44	2.67	4.9	3.73	3.53	3.19
Histidine	1.54	2.0	2.4	2.7	1.7	2.0	0.51	4.15	1.8	1.06	0.90	3.96
Isoleucine	4.70	4.8	4.7	4.3	5.1	4.2	3.56	1.58	3.2	1.89	1.66	0.90
Leucine	7.70	8.1	7.5	7.1	7.4	7.2	6.46	2.40	5.7	3.44	3.05	10.12
Lysine	5.87	7.2	7.7	8.0	0.2	6.9	1.63	3.09	6.6	3.43	2.98	5.99
Methionine	2.90	3.0	2.8	2.4	2.6	2.9	0.48	0.63	2.5	0.76	0.66	0.91
Phenylalanine	4.20	3.8	3.9	3.4	3.2	3.5	3.14	1.58	2.9	1.93	1.73	5.47
Threonine	4.40	5.2	4.2	4.0	4.2	4.1	0.38	1.64	3.1	1.79	1.69	1.02
Tryptophan	-	-	-	-	-	-	0.52	0.90	1.1	0.87	0.77	1.73
Valine	5.40	5.3	5.8	4.9	-	4.6	6.03	2.04	4.3	2.64	2.38	6.41
Tyrosine	1.20	1.0	1.1	0.7	0.9	-	-	-	-	-	-	-

*Percent of crude protein

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

TABLE 9

Apparent nutrient digestibility (%) of various ingredients of animal origin by various aquatic species

Feed ingredients/aquatic species	Dry matter	Crude protein	Crude lipid	Gross energy	P
Fishmeal (local)[1]					
Seabass	62.03	92.30	89.40	83.96	85.52
Grass carp	81.51	84.04	83.83	-	-
Chinese long-snout catfish	-	90.91	83.00	-	-
Black carp	68.17	88.38	81.65	79.16	12.62
Fishmeal (imported)[1]					
Grass carp	83.06	87.54	80.56	-	-
Nile tilapia	-	92.21	-	-	-
Fleshy prawn	-	91.47	-	-	-
Blunt nose black bream	64.20	83.90	98.10	-	-
Black carp	77.35	89.30	100.00	91.54	-
Poultry feather meal[2]					
Nile tilapia	-	93.36	-	-	-
Fleshy prawn	-	76.42	-	-	-
Blunt nose black bream	62.20	86.90	-	-	-
Meat & bone meal[3]					
Seabass	58.62	77.39	88.31	67.94	53.39
Blunt nose black bream	70.00	89.10	91.80	-	15.00
Black carp	71.39	88.00	97.00	79.66	25.42
Grass carp	59.13	79.21	81.36	-	-
Fleshy prawn	-	81.35	-	-	-
Meat meal[3]					
Seabass	70.10	87.30	82.80	-	-
Pacific white shrimp	76.00	90.00	-	-	-
Blood meal[4]					
Nile tilapia	-	91.58	-	-	-
Blunt nose black bream	88.00	83.38	0.22	-	0.24
Black carp	85.42	92.19	-	86.62	-
Chinese long-snout catfish	-	85.93	-	82.27	-
Fleshy prawn	-	73.47	-	-	-

Source: [1] Chang *et al*. (2005); Lei, Yang and He (1996); Lin, Luo and Ye (2001); Liu, Zhu and Chen (1990); Rong, Liang and Yue (1994); Ye, Lin and Luo (2003); You *et al.,* (1993); Wu *et al.,* (1995); Wu *et al.,* (2000), [2]Rong, Liang and Yue (1994); Wu *et al,* (1995); Wu *et al,* (2000); [3]Chang *et al.* (2005); Lin, Luo and Ye (2001); Liu, Zheng and Zhao (2004); Rong, Liang and Yue (1994); [4]Lei, Yang and He (1996); Liu, Zhu and Chen (1990); Rong, Liang and Yue (1994); You *et al*. (1993); Wu *et al.* (1995); Wu *et al.* (2000)

TABLE 10

Apparent amino acid digestibility (%) of various ingredients of animal origin by various aquatic species

Ingredients/species	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Try	Val	Tyr	Cys
Fishmeal (local)[1]												
Seabass	94.37	83.32	91.41	90.53	89.03	89.58	90.85	93.63	-	92.34	-	-
Grass carp	84.90	93.10	87.50	85.50	90.50	93.80	74.9	90.10	-	89.80	-	-
Fishmeal (imported)[1]												
Grass carp	86.70	90.00	98.90	87.30	91.30	90.90	98.10	85.30	-	88.60	-	-
Nile tilapia	94.90	93.60	92.10	91.30	93.20	94.60	90.50	92.30	-	90.80	92.70	85.90
Fleshy prawn	90.91	91.02	90.96	90.92	90.91	60.91	90.92	90.82	-	90.84	-	-
Poultry feather meal[2]												
Nile tilapia	94.50	59.30	96.20	94.20	56.50	89.90	93.60	92.50	-	95.80	91.50	90.80
Fleshy prawn	76.42	77.95	76.43	76.39	76.61	76.49	76.41	76.42	-	76.37	-	-
Meat & bone meal[3]												
Seabass	82.79	81.41	75.47	79.12	82.57	79.03	75.28	74.57	-	77.95	-	-
Meat meal[3]												
Grass carp	80.40	87.00	74.00	84.60	79.00	88.50	71.00	84.20	-	81.40	-	-
Fleshy prawn	81.47	81.34	81.37	81.35	81.89	81.18	81.30	81.35	-	81.35	-	-
Blood meal[4]												
Nile tilapia	93.90	95.50	-	91.90	90.40	78.10	92.30	87.20	-	90.60	-	-
Fleshy prawn	49.70	40.49	49.57	49.30	50.32	49.45	49.27	49.76	51.56	49.70	-	-

Source: [1]Chang *et al.* (2004); Liu, Zheng and Zhao (2004); Rong, Liang and Yue (1994); Wu *et al.* (2000), [2]Rong, Liang and Yue (1994); Wu *et al.* (2000), [3]Chang *et al.* (2004); Rong, Liang and Yue (1994); Ye, Lin and Luo (2003), [4]Rong, Liang and Yue (1994); Wu *et al.* (2000)

TABLE 11

Chemical composition (percent dry matter) of major plant feed ingredients and single cell proteins

Ingredients	Dry matter	Crude protein	Crude lipid	Ash	Crude fibre	NFE	Ca	P
Plant based feed ingredients								
Rape seed meal	89.0	36.5	3.5	4.8	11.7	20.5	0.68	1.17
Soybean meal, solvent extracted	89.5	44.5	1.0	6.0	6.5	-	0.25	0.60
Soybean meal, expeller	89.0	42.0	4.0	6.0	6.0	-	0.25	0.60
Peanut meal, solvent extracted	91.0	47.0	1.0	5.5	-	-	0.20	0.60
Peanut meal, expeller	91.0	45.0	5.0	5.5	4.2	-	0.20	0.55
Peanut meal with hull	88.6	29.3	9.9	6.3	27.9	-	0.26	0.29
Wheat flour	89.0	13.0	2.0	1.8	3.0	-	0.05	0.40
Wheat bran	87.5	15.5	4.0	6.0	10.5	-	0.10	1.15
Wheat middling	87.5	15.5	4.0	4.5	7.5	-	0.10	0.90
Wheat germ	89.5	25.0	8.0	4.5	3.0	-	0.05	1.00
Rice bran, de-fatted	89.0	15.5	1.0	8.0	8.5	-	0.10	1.40
Rice bran, full-fat	89.5	13.0	14.0	16.7	12.0	-	0.10	1.60
Rice hull	91.5	3.0	0.7	22.8	39.3	-	-	-
Single cell protein								
Brewer’s yeast	91.7	51.4	0.6	8.4	2.0	29.3	-	-
Torula yeast	91.7	47.1	1.1	6.9	2.0	34.6	-	-
Molasses yeast	95.5	42.5	2.8	8.8	0.5	47.2	-	-
Brewers grain	92.5	25.0	6.0	4.0	15.0	-	0.25	0.48

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

TABLE 12
Amino acid profile (percent dry matter) of major plant feed ingredients and single cell proteins

Amino acids	Cotton seed meal, solvent extracted	Cotton seed meal, expeller	Rape seed meal	Soybean meal, solvent extracted	Soybean meal, expeller	Peanut meal, solvent extracted	Peanut meal, expeller	Wheat bran	Wheat middling	Wheat germ	Rice bran, full-fat	Brewer's yeast	Torula yeast	Molasses yeast	Brewers grain
Arginine	4.47	4.51	2.23	3.07	2.93	4.62	4.05	0.87	1.21	1.88	0.85	2.46	2.60	2.27	1.22
Histidine	1.04	1.07	1.09	0.86	1.00	0.93	0.85	0.36	0.45	0.65	0.32	1.00	1.40	1.11	0.49
Isoleucine	1.28	1.39	1.46	1.70	1.74	1.69	1.70	0.70	0.57	0.88	0.51	2.94	2.90	2.70	1.47
Leucine	2.23	2.35	2.71	3.05	3.07	2.61	2.62	1.09	1.09	1.56	0.90	3.56	3.50	3.89	1.89
Lysine	1.81	1.64	2.15	3.53	2.27	1.62	1.33	0.67	0.81	1.54	0.57	3.70	3.80	3.76	0.87
Methionine	0.52	0.57	0.77	0.65	0.46	0.42	0.50	0.20	0.28	0.44	0.24	1.0	0.80	0.84	0.45
Phenylalanine	2.21	2.18	1.54	1.89	1.94	1.99	1.95	0.64	0.67	0.94	0.58	2.77	3.00	2.46	1.38
Threonine	1.23	1.36	1.71	1.00	0.66	-	-	0.53	0.60	0.97	0.47	2.41	2.60	2.82	0.97
Tryptophan	0.47	0.53	0.49	1.37	1.46	1.09	1.17	0.39	0.23	0.30	0.10	0.73	0.50	0.59	0.37
Valine	1.82	1.97	1.94	0.93	1.78	1.79	1.89	0.68	0.83	1.17	0.76	2.90	2.90	2.97	0.40

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

TABLE 13
Apparent nutrient digestibility (%) of major plant feed ingredients by various aquatic species

Feed ingredients/ aquatic species	Dry matter	Crude protein	Crude lipid	Carbohydrate	Crude fibre	Gross energy	P
Cotton seed meal[1]							
Seabass	40.59	76.79	80.46	-	-	16.99	-
Grass carp	59.49	75.22	51.16	-	-	-	8.50
Blunt nose black bream	43.80	81.20	90.40	23.4	-	-	-
Black carp	64.60	85.50	57.00	60.0	18.0	-	-
Fleshy prawn	-	83.14	-	-	-	-	-
Rapeseed meal[2]							
Seabass	58.66	81.30	86.09	-	-	68.01	-
Grass carp	68.62	77.81	81.33	-	-	-	-
Blunt nose black bream	49.30	80.70	85.70	45.7	-	-	8.20
Black carp	61.59	86.42	98.80	63.0	18.0	65.93	43.41
Chinese long-snout catfish	-	89.87	-	-	-	79.07	-
Nile tilapia	-	86.57	-	-	-	-	-
Fleshy prawn	-	80.16	-	-	-	-	-
Soybean meal[3]							
Seabass	66.00	90.60	86.70	-	-	76.20	47.50
Grass carp	75.40	87.50	82.20	-	-	-	-
Blunt nose black bream	77.80	95.70	-	74.4	-	-	39.70
Black carp	79.30	96.80	-	67.1	-	81.30	64.40
Chinese long-snout catfish	-	76.30	-	-	-	61.40	-
Fleshy prawn	-	92.00	-	-	-	-	-
Peanut meal, solvent extracted[4]							
Seabass	64.40	87.05	87.21	-	-	73.16	59.20
Blunt nose black bream	-	95.70	-	74.4	-	-	39.70
Peanut meal with hull[4]							
Blunt nose black bream	29.50	86.20	-	45.3	-	-	11.50
Black carp	46.04	88.93	-	51.3	-	51.44	22.27
Nile tilapia	-	89.87	-	-	-	-	-
Fleshy prawn	-	86.94	-	-	-	-	-

Source: [1] Chang *et al.* (2005); Lin, Luo and Ye (2001); Liu, Zheng and Zhao (2004); Rong, Liang and Yue (1994); You *et al.* (1993); Wu *et al.* (1995); Wu *et al.* (2000 [2]Chang *et al.* (2005); Lei, Yang and He (1996); Lin, Luo and Ye (2001); Liu, Zhu and Chen (1990); Rong, Liang and Yue (1994); You *et al.* (1993); Wu *et al.* (1995); Wu *et al.* (2000), [3] Chang *et al.* (2005); Lei, Yang and He (1996); Lin, Luo and Ye (2001); Liu *et al.* (1990); Rong, Liang and Yue (1994); You *et al.* (1993); Wu *et al.* (1995), [4]Chang *et al.* (2005); Liu, Zhu and Chen (1990); Rong, Liang and Yue (1994); You *et al.* (1993); Wu *et al.* (1995)

TABLE 14
Apparent nutrient digestibility (%) of major plant feed ingredients and single cell protein by various aquatic species

Feed ingredients/aquatic species	Dry matter	Crude protein	Crude lipid	Carbohydrate	Gross energy	P
Wheat flour						
Grass carp	59.97	87.06	82.49	-	-	-
Chinese long-snout catfish	-	94.17	-	-	48.43	-
Wheat bran[1]						
Grass carp	62.61	73.20	52.42	-	-	-
Black carp	42.81	87.16	99.30	37.45	33.95	33.96
Nile tilapia	-	91.54	-	-	-	-
Wheat middling[1]						
Grass carp	61.64	71.53	53.22	-	-	-
Nile tilapia	-	89.03	-	-	-	-
Barley flour[1]						
Grass carp	59.97	59.36	50.09	-	-	-
Black carp	66.90	74.60	82.80	71.50	-	-
Rice bran, de-fatted[2]						
Grass carp	47.41	76.36	56.99	-	-	-
Rice bran, full-fat[2]						
Nile tilapia	-	60.48	-	-	-	-
Blunt nose black bream	61.00	74.90	86.80	65.10	-	3.00
Brewer's yeast[3]						
Nile tilapia	-	91.69	-	-	-	-
Grass carp	64.24	85.04	82.53	-	-	-
Fleshy prawn	-	84.75	-	-	-	-
Torula yeast[3]						
Fleshy prawn	-	87.63	-	-	-	-
Molasses yeast[3]						
Fleshy prawn	-	74.22	-	-	-	-
Brewers' grain[4]						
Grass carp	71.71	68.47	69.09	-	-	-

Source: [1]Lei, Yang and He (1996); Liu, Zhu and Chen (1990); Lin *et al.* (2001); You *et al.* (1993); [2]Lin *et al.* (2001); Wu *et al.* (1995); Wu *et al.* (2000), [3]Lin, Luo and Ye (2001); Rong, Liang and Yue (1994); Wu *et al.* (2000), [4]Lin, Luo and Ye (2001)

TABLE 15
Apparent amino acid digestibility (%) of major plant feed ingredients by various aquatic species

Feed ingredients/ aquatic species	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Try	Val
Cotton seed meal[1]										
Seabass	93.59	83.97	80.82	82.89	77.32	60.30	86.46	79.25	-	76.99
Grass carp	89.20	73.70	89.50	84.10	87.80	86.10	65.30	87.2	-	88.50
Nile tilapia	94.70	89.90	80.20	82.90	75.20	59.90	89.90	85.4	-	87.20
Fleshy prawn	83.11	83.19	83.08	83.14	83.23	82.97	83.12	83.08	83.21	83.27
Rape seed meal[2]										
Seabass	91.87	91.64	82.55	84.32	89.93	75.95	88.09	83.62	-	81.72
Grass carp	84.80	88.30	81.60	83.60	91.50	87.60	72.70	83.00	-	81.80
Nile tilapia	94.90	93.70	86.90	83.90	78.80	89.30	86.40	80.20	-	81.80
Fleshy prawn	80.28	80.34	80.25	80.20	80.21	80.60	80.15	80.07	80.93	80.32
Soybean meal[3]										
Seabass	97.34	97.89	92.35	90.66	93.96	70.05	91.72	91.49	-	88.10
Grass carp	84.90	88.50	66.50	83.60	90.50	85.60	64.90	82.10	-	82.80
Nile tilapia	99.40	98.20	94.20	96.40	96.30	94.90	96.40	96.90	-	94.20
Fleshy prawn	92.13	92.22	92.07	92.11	92.06	92.25	92.12	91.90	92.06	92.11
Peanut meal, solvent extracted[4]										
Seabass	97.34	97.89	92.35	90.66	93.96	70.05	91.72	91.49	-	88.10
Peanut meal, expeller[4]										
Fleshy prawn	87.00	87.16	87.06	87.02	87.14	87.06	86.96	86.97	87.34	87.01
Peanut meal with hull[4]										
Nile tilapia	97.00	87.20	80.10	86.20	95.20	85.70	87.80	85.70	-	
Wheat flour[4]										
Grass carp	93.00	90.40	82.90	89.60	90.10	87.80	83.60	80.20	-	86.30
Wheat bran[4]										
Grass carp	76.20	91.10	94.80	87.10	86.90	90.00	77.20	85.40	-	79.30
Nile tilapia	97.80	97.40	94.10	92.70	93.50	88.20	91.10	94.20	-	87.10
Fleshy prawn	72.34	73.68	73.00	72.46	72.75	72.05	73.13	75.03	73.34	72.46
Wheat middlings[4]										
Grass carp	75.90	82.20	82.90	79.40	89.80	90.20	84.60	71.00	-	87.10
Nile tilapia	99.10	100.00	92.50	94.90	96.10	88.20	95.60	-	-	91.80

Source: Chang *et al.* (2004); Lin *et al.* (200); You *et al.* (1993); Wu *et al.* (2000), [2] Chang *et al.* (2004); Lin *et al.* (200); Rong, Liang and Yue (1994); Wu *et al.* (2000), [3] Chang *et al.* (2004); Lin *et al.* (2000); Rong, Liang and Yue (1994); Wu *et al.* (2000), [4] Chang *et al.* (2004); Rong, Liang and Yue (1994); Wu *et al.* (2000)

TABLE 16
Apparent amino acid digestibility (%) of major plant feed ingredients and single cell proteins by various aquatic species

Single cell protein/aquatic species	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Val	Tyr	Cys
Barley flour[1]											
Grass carp	82.8	82.3	84.5	82.9	80.2	79.2	74.5	74.9	-	73.0	-
Rice bran, full-fat[2]											-
Grass carp	88.2	90.9	87.7	88.4	90.0	88.6	73.4	84.1	-	90.0	-
Nile tilapia	74.2	84.8	89.0	63.6	60.4	72.9	76.6	62.5	-	67.3	-
Brewer's yeast[3]											
Nile tilapia	93.3	88.9	82.4	89.3	76.2	92.4	90.3	85.9	86.4	86.6	81.9
Grass carp	87.9	38.1	25.1	60.1	94.8	31.6	67.9	54.9	85	35.0	-
Fleshy prawn	84.8	84.8	84.8	84.8	84.8	84.8	84.8	84.9	84.3	-	-
Torula yeast[3]											-
Fleshy prawn	87.6	87.8	86.7	87.7	87.7	88.2	87.6	87.8	87.7	-	-
Molasses yeast[3]											-
Fleshy prawn	74.3	74.2	74.2	74.3	74.5	74.1	74.3	74.2	74.4	-	-
Brewers' grain[4]											-
Grass carp	83.4	86.1	86.8	85.6	84.7	88.0	75.8	74.6	78.1	-	-

Source: [1]Liu *et al.* (2000); Rong, Liang and Yue (1994); Wu *et al.* (2000), [2]Liu, Zheng and Zhao (2004); Wu *et al.* (2000), [3]Rong, Liang and Yue (1994); Ye *et al.* (2003); Wu *et al.* (2000), [4]Liu, Zheng and Zhao (2004)

TABLE 17
Mineral content of major feed ingredients

Minerals	Unit	Meat meal	Meat & bone meal	Blood meal	Soybean meal, solvent extracted	Soybean meal, expeller	Peanut meal, solvent extracted	Peanut meal, expeller	Wheat middling	Wheat germ
Calcium	%	7.96	10.16	0.27	0.25	0.33	0.20	0.16	0.11	0.07
Phosphorus	%	4.00	4.86	0.26	1.71	0.62	0.63	0.56	0.83	0.64
Sodium	%	1.31	0.73	0.32	0.12	0.24	0.42	0.41	0.20	-
Potassium	%	0.57	1.58	0.14	0.07	0.02	1.14	1.13	0.97	0.83
Magnesium	%	0.27	1.13	0.22	0.28	0.25	0.04	0.32	0.24	0.23
Chlorine	%	1.20	0.74	-	0.60	1.91	-	0.03	0.08	-
Sulphur	%	0.50	0.26	0.34	0.22	0.33	26.8	0.29	0.24	-
Manganese	mg/kg	9.6	13.3	5.3	29.9	32.3	0.03	25.4	112.2	-
Iron	mg/kg	0.044	0.050	0.307	0.008	0.0016	32.7	-	0.008	-
Zinc	mg/kg	104.4	95.3	4.4	-	-	15.3	-	150.2	-
Copper	mg/kg	9.8	1.5	13.3	15.8	18.0	-	-	18.3	-
Selenium	mg/kg	0.420	0.262	-	-	-	0.065	-	-	-
Iodine	mg/kg		1.313	-	-	-	-	-	0.109	-

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

TABLE 18
Vitamin content of major feed ingredients

Vitamins	Unit	Blood meal	Soybean meal, solvent extracted	Soybean meal, expeller	Peanut meal, solvent extracted	Peanut meal, expeller	Brewer's yeast	Torula yeast
A (Retinol)	IU/g	-	0.7	0.3	-	0.4	-	-
E (α-tocopherol)	mg/kg	-	-	6.6	-	-	-	-
B_1 (Thiamine)	mg/kg	0.4	1.5	4.0	5.7	7.1	90.3	6.2
B_2 (Riboflavin)	mg/kg	2.5	4.0	3.5	10.9	5.2	36.4	49.2
B_3 (Nicotinic acid)	mg/kg	31.0	14.1	14.9	172	166	458	499
B_5 (Pantothenic acid)	mg/kg	2.9	14.1	14.9	50.2	47.2	109.0	83.1
B_6 (Pyridoxine)	mg/kg	4.43	-	-	-	-	43.24	29.54
B_7 (Biotin)	mg/kg	0.08	0.73	0.30	0.33	-	0.96	1.39
B_9 (Folic acid)	mg/kg	0.10	-	6.60	0.65	-	9.42	22.4
B_{12} (Cyanocobalamin)	mg/kg	44.3	-	-	-	-	-	-
Choline	mg/kg	729	2 551	2 763	1 963	1 650	4 075	2 887

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

3. FEED MANAGEMENT STRATEGIES AND POND MANAGEMENT TECHNIQUES

Enhanced levels of intensity in virtually all aquaculture sectors have led to enormous increases in the demand for feeds. Moreover, price escalations of feed ingredients have also increased the share of feed cost in the total production costs.

To ease the problems of feed supply and to minimize feed costs, various management strategies and pond management techniques have been developed and adopted. These have made a significant contribution to the sustainable development of the industry.

3.1 Nutritional requirements of major aquaculture species in China

Understanding the nutritional requirements of cultured animals is the fundamental basis for good feed management practices at the industrial and small-scale level. Intensive research on the nutritional requirements of common aquaculture species was undertaken during 1980–1990s and this was strongly driven by the early developments in compound aquafeed production. Many of these findings are still used by the feed industry and are presented in Tables 19 to 23.

TABLE 19
Nutritional requirements (percent dry matter) of important aquacultures species in China

Species	Crude protein			Crude lipid	Carbohydrate	Crude fibre
	Fry	Juvenile	Adult			
Common carp	43–47	37–42	28–32	4.6	38.5	3.7–7.0
Black carp	33–41	29.5–40.9	35	4.6	25–38.5	
Grass carp	25–30	28–32		4.2–4.8	36.5–42.5	12.0
Wuchang bream	25.6–41.4	21.1–30.6		4.5	25–28	36.5–42.5
Crucian carp	40.0	30.0	28	5–8	36.0	12.2
Rainbow trout	43.0	36–40	35–40	8.5	20–30	3.0
Nile tilapia	48.5			12–15	30–40	5–20
Japanese eel	48.5	45.0	44	5–8	18.3–27.3	
Channel catfish	35–40	30–35	28–35	5–12	40.0	
Black porgy	40–45			10–14	15.0	6.25

Source: modified after Li (1996)

TABLE 20
Nutritional requirements (percent dry matter) of fleshy prawn, *Penaeus chinensis* and black tiger shrimp, *Penaeus monodon*

Species	Crude protein			Crude lipid	Carbohydrate	Crude fibre	Ca	P	C/P ratio
	Post larvae	Juvenile	Adult						
Fleshy prawn	40	42	44	4–6	20–26	3.7–7.0	1.0–1.5	1.7–2.5	1:1.7
Tiger shrimp	40–44	40	35–38	4		3–5	3.5–4.5	3.5–4.5	

Post larvae 0.7–1.0 cm, juvenile 3.0–6.0 cm and adult >6 cm.
Source: modified from Li, Song and Lou (1986), Li (1990) and Li (1996)

TABLE 21
Nutritional requirements (percent dry matter) of giant freshwater prawn, *Macrobrachium rosenbergii*

Nutrient	Juvenile (1–4 cm)	Early growout (4–6 cm)	Late growout (>6 cm)
Crude protein	40–45	35–40	28–35
Crude lipid	7–9	5–7	4–5
Carbohydrate	20–24	24–30	30–35
Crude fibre	4	5	6
Crude ash	10–12	12–14	14–16
Calcium	0.9–1.1	1.8–2.2	1.8–2.2
Phosphorus	0.9–1.1	1.8–2.2	1.8–2.2

Source: adapted from Li (1996)

TABLE 22
Nutritional requirements (percent dry matter) of soft-shelled turtle

Crude protein		Crude lipid	Carbohydrate	Crude fibre
Juvenile	Adult			
47.4–49.1	43.3–45.1	6–7	22.7–25.3	<10

Source: adapted from Li (1996)

TABLE 23
Nutritional requirements (percent dry matter) of Nile tilapia

Fish weight (g)	Crude protein	Crude lipid	Carbohydrate
0.1–2.5	56–40	<12	40–50
2.5–7.5	40–36	<10	-
7.5–30.0	36–30	<8	-
> 30.0	32–25	<5	-

Source: Unpublished data of YSFRI (Yellow Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences)

Since the mid-1990s, there has been a rapid diversification in aquaculture species to meet the changing preferences of consumers and to increase profits. Unfortunately since that time government has reduced the level of funding for aquaculture nutrition research. As a consequence, research on the nutrient requirements of many new species is lagging behind. The feed additive industry in China is very profitable and is driving research towards understanding the amino acid, vitamin and mineral requirements of aquatic species and hence much of the research is focused on these aspects. See Annexure 1 for information on the amino acid, mineral and vitamin requirement of the major aquaculture species. The current lack of systematic research on the nutritional requirements of aquaculture species will certainly impact on development of compound aquafeeds.

3.2 Farm-made feeds

Traditional fish farming practices mainly relied on natural food organisms, enhanced by organic fertilization and supplementary feeds such as aquatic weeds, terrestrial grasses, naturally collected molluscs and by-products/wastes from agricultural production and processing activities. Due to the intensification of fish farming and the introduction of new species, aquaculture has become more dependent on artificial feeds. The use of commercially manufactured pellets is becoming more popular, although farm-made feeds still play and enormously important role in Chinese aquaculture.

Because of the diversity of farmed species there are many different types of farm-made feeds. In general, farm-made or processed feeds can be classified into several categories.

3.2.1 Simple processed raw feed ingredients and natural food organisms

These feeds are commonly used in semi-intensive farming of marine fish, crabs and prawns and may include soaked soybean, maize and soybean/rapeseed cake, crushed molluscs, chopped trash fish or mussel meat, germinated barley, soybean milk and dregs.

3.2.2 Compound farm-made feeds

Some farmers produce a compound pellet using on-farm produced ingredients according to several formulations. Most of these feeds are nutritionally unbalanced. On the other hand, some very well balanced feeds are produced, especially for high value species such as eel, puffer fish and some marine fish species.

3.2.3 Custom made compound pellets

These feeds are made by small and medium-scale feed manufacturers who have specialized their operations such that they can make smaller quantities of feeds according to their own or their clients' formulation and specifications.

3.2.4 Comparison between farm-made feeds and industrially manufactured pellets

There are no statistical data on the proportional use of farm-made and commercially manufactured feeds in China. However, it is estimated that just less than 8 million tonnes of commercially manufactured aquafeeds were used in 2004. Farm-made feeds (all types, including the feeds made by small and medium-scale processors) therefore play a far more important role in aquaculture than industrial aquafeeds. It is not possible to provide an estimate of annual farm-made feed production and use. Export of aquafeeds from China is very limited and imports mainly comprise starter feeds for shrimp and eel. However, it is difficult to estimate total exports and imports.

In comparison to commercially manufactured feeds, farm-made feeds have certain advantages and disadvantages. The manufacture of farm-made feed usually requires more time because of primitive equipment with a limited production capacity. Most commercial feed manufacturers have established convenient retailing chains for farmers, except in remote areas with poor transport facilities. Farm-made feeds are often in the form of moist pellets, paste/dough or fresh or in other forms that can not be stored for as long as sinking or expanded (floating) pellets.

Farm-made/processed feeds and commercially manufactured feeds are often used for different species or in different practices. Practical feed conversion ratios of different farm-made feeds are seldom compared and because of the different formulations and ingredients used it is difficult to compare the biological and economic efficiency of these feeds with commercially manufactured feeds.

3.3 Pond management techniques

As mentioned earlier, pond aquaculture is the most important practice in terms of aquaculture production. Many practical techniques to minimise feed costs have been developed by scientists and farmers and in particular these have focused on reducing feed use and improving feed utilization.

Fertilization

Pond fertilization throughout the culture cycle was a common practice in extensive and semi-intensive polyculture of carp species and, if applied appropriately, this practise can reduce feed requirements to a minimum. However, the trend of increasing intensification has led to significant increases in the use of artificial feeds, such that the role of fertilizers in pond aquaculture has become less important than before, especially during growout. However, fertilization is still the major approach to provide food during seed production operations of many species. The fertilization of ponds during the preparation phase is also still commonly practiced in carp and shrimp/prawn culture. Commonly used fertilizers in ponds include pig, chicken, duck manure, cow dung and green fodder. During pond preparation the base quantity is between 2 250–3 750 kg pig manure/ha and if ponds are fertilized during the production cycle then quantities ranging from 1 500–2 250 kg/ha are used for each application.

Inorganic fertilization is commonly practiced in many small irrigation reservoirs to enhance natural productivity and to increase fish production. N and P fertilizers are commonly used and the recommended dose is usually 0.5 mg/l for N and 0.05 mg/l for P.

Pond substratum management

Improving the pond substratum is another important management technique, which is directly related to feed management strategies. It usually consists of three activities, total drainage, sun drying and liming. These practices promote the decomposition of organic matter in the bottom soil and accelerate the release of nutrients soon after filling, leading to enhanced production of natural food organisms and a reduction in artificial feed requirements. Managing the pond substratum also results in improved water quality during the production cycle, particularly higher DO levels and this contributes to improved feed utilization and growth. Excessive bottom silt is mechanically removed. This minimises the accumulation of organic matter leading to improved water quality.

In super-intensive systems, especially for shrimp, the bottom is lined with plastic and central draining pipes are installed that enables the removal of all wastes produced during the culture cycle. Bottom aeration systems have also been introduced into super-intensive shrimp culture ponds (up to 20–30 tonnes/ha/cycle)

Water quality maintenance: aeration and water exchange

Feed utilization efficiency is highly influenced by water quality, especially DO levels. Aeration is the most commonly used method to maintain good water quality in semi-intensive and intensive culture practices. Three different types of aerators are commonly used in China, paddle-wheels, turbines and water jets. The former is commonly used in shrimp ponds and the latter two types are commonly used in fishponds. These range from modern types that are internationally available to ingenious home made devices (Figures 12, 13 and 14).

FIGURE 12
Paddle wheel aerators in freshwater semi-intensive culture pond of Pacific white shrimp, Suzhou city, Jiangsu province

FIGURE 13
Farm-made paddle wheel aerator used in brackish-water, semi-intensive shrimp culture, Beihai city, Guangxi Autonomous Region

FIGURE 14
Turbine type aerators and water pump in a freshwater semi-intensive culture pond of giant freshwater prawn, Gaoyou city, Jiangsu province

Water exchange is practiced only when water quality can not be effectively maintained through aeration or other methods and this is because it requires more energy and is subject to availability.

Use of beneficial micro-organisms
Since the late 1990s, new methods for water quality maintenance have been widely adopted in China and this involves the use of beneficial micro-organisms. Two types are commonly used, viz. photosynthetic bacteria and EM (effective micro-organisms). The micro-organisms have two major functions, viz. improvement of water quality and prevention of disease by decreasing the levels of NH_3 and NO_2 and increasing DO levels in the water. Some bacteria also directly improve feed utilization.

3.4 Feed formulation

Increased intensification in aquaculture has significantly increased the quantity of feed used. Many aquaculture practices are now entirely dependent on artificial feeds. To improve feed utilization, traditionally used raw feed stuffs (mostly by-products from grain processing and oil extraction) are being replaced by commercially manufactured compound feeds. Many of the formulations are considered confidential, although some commonly used ones are listed in Tables 24 to 34.

TABLE 24
Practical feed formulation for Nile tilapia

Ingredients	Ingredient composition (% dry matter)		
	Fry (0.1–1.0 g)	Fingerling (10–50 g)	Growout (>50g)
Fishmeal	50.0	12.0	4.0
Soybean meal	17.0	46.0	34.0
Wheat middling	4.0	30.0	30.0
Wheat meal	4.2	-	-
Corn	-	6.2	22.1
Corn gluten meal	12.0	-	-
Poultry by-product meal	2.0	-	6.0
Vegetable oil	-	3.6	0.5
Fish oil	1.0	-	-
Fish protein hydrolysate	4.0	-	-
Phosphate	-	1.4	2.6
Vitamin & mineral premix	0.5	0.5	0.5
Binder	-	-	0.01
Methionine	-	-	0.01
Proximate composition (% dry matter)			
Dry matter	91.0	90.0	88.3
Crude protein	49.5	35.0	28.5
Crude fat	13.0	12.4	11.9
Approximate cost (US$/tonne)	400	300	250

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 25
Practical feed formulation for grass carp and wuchang bream

Ingredient	Ingredient composition (% dry matter)	
	Fingerling	Growout
Corn	8.95	12.95
Wheat bran	10.0	11.0
Low-grade wheat flour	18.8	16.8
Soybean cake	14.0	5.0
Rape seed cake	41.0	51.0
Fishmeal	4.0	-
Binder	1.0	1.0
Growth and immune enhancing additive mix	1.25	1.25
Coarse powder*	1.0	1.0
Approximate cost (US$/tonne)	300	

*Mineral powder for better pelleting and ingredient mixing
Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 26
Practical feed formulation for common carp, crucian carp and Nile tilapia

Ingredient	Ingredient composition (% dry matter)	
	Fingerling	Growout
Corn	6.9	10.0
Wheat bran	-	4.0
Low grade wheat flour	11.85	11.75
Soybean cake	32.0	27.0
Rape seed cake	40.0	41.0
Fishmeal	6.0	3.0
Binder	1.0	1.0
Growth and immune enhancing additive mix	1.25	1.25
Coarse powder*	1.0	1.0
Approximate cost (US$/tonne)	300	250

*Mineral powder for better pelleting and ingredient mixing
Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 27
Practical feed formulation for turbot, flounder and red sea bream (growout)

Ingredient	Ingredient composition (percent dry matter)		
	Turbot[1]	Flounder[1]	Red sea bream[2]
Fishmeal	45.0	42	30
Hydrolyzed protein	5.0	10	
Blood meal	5.0		
Silage			4.0
Yeast	5.0	10	5
Groundnut/peanut meal	10.0	10	16
Soybean cake	10.0	10	16
Wheat flour	15.5	13	
Wheat middling			15
Fish oil	1.0		4
Calcium diacid phosphate	2.0	2	
Dicalcium monophosphate			2
Phosphatid	1.0	1.5	
Phospholipid			1.5
Choline	0.5	0.5	0.5
Vitamin mix	0.5	0.5	1.0
Mineral mix	0.5	0.5	1.0
Proximate composition (% dry matter)			
Dry matter	87.3	84.22	
Crude protein	47.6	45.5	
Crude lipid	7.1	7.03	
Ash	10.7	10.37	
Approximate cost (US$/tonne)	800–900	800–900	

Source: [1]Yellow Sea Fisheries Research Institute Feed Company, Qingdao, Shandong Province (pers. comm.); [2]Lei (2005)

TABLE 28
Practical feed formulation for eel (percent dry matter)

Ingredient	Glass eel 0	Glass eel 1	Black eel	Juvenile	Growout
White fishmeal	68.0	68.0	66.0	60.0	52.0
Red fishmeal	2.0	2.0	2.0	5.0	10.0
Popped soybean	-	-	-	4.7	7.2
Potato starch	20.0	20.0	10.0	-	-
Cassava starch	-	-	12.2	2.25	23.0
Hydrolyzed protein	1.2	1.2	3.5	3.5	3.5
Yeast	2.0	2.0	2.0	2.0	2.0
Calcium diacid phosphate	0.2–0.3	0.2–0.3	0.2–0.3	0.2–0.3	0.2–0.3
Vitamin	0.3	0.3	0.25	0.2	0.15
Mineral mix	1.0	1.0	1.0	1.0	1.0
50% chloridised choline	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5
Salt	0.2	0.2	0.2	0.3	0.3
Lysine	0.2	0.2	0.15	0.15	0.125
Methionine	0.1	0.1	-	0.1	0.075
Lysine	0.15	0.15	0.1	0.1	0.1
Growth enhancing agent	0.05	0.05	0.05	-	-
Casein		4.0	-	-	-
Fish meat protein	4.0	-	2.0	-	-
Approximate cost (US$/tonne)	1500–1600	1500–1600	1250–1400	1050–1200	950–1050

Source: He Yijing, feed manufacturer in Guangdong province (pers. comm.)

TABLE 29
Practical feed formulation for Pacific white shrimp, *Litopenaeus vannamei*

Ingredient	Ingredient composition (% dry matter)		
	Starter	Growout 2	Growout 3
Wheat meal	29.5	28.6	30.6
Soybean cake	15.0	15.0	15.0
Groundnut cake	11.0	16.0	16.0
Fishmeal	30.0	25.0	23.0
Squid meal	3.0	2.0	2.0
Shrimp bran*	0	1.0	1.0
Yeast	3.0	3.0	3.0
Bone meal	1.1	-	-
Calcium phosphate	2.0	2.0	2.5
Calcium diacid phosphate	1.5	1.5	2.0
Binder	1.2	1.2	1.0
Growth and immune enhancing additive mix	1.0	1.0	1.0
Fish oil	1.0	1.0	1.0
Sea salt	1.5	1.5	1.5
Lure agent	0.1	0.1	0.1
FRC**	0.1	0.1	0.1
Polysaccharide	0.1	0.1	0.1
High stability Vitamin C	0.1	0.1	0.1
Approximate cost (US$/tonne)	850–950	750–800	650–700

*By-product from shrimp processing industry; **a commercial herb additive for increasing resistance to disease and stress.

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 30
Practical feed formulation for flounder, shrimp, Nile tilapia and carp (percent dry matter)

Ingredient	[1]Flounder	[2]Shrimp	[3]Tilapia	[4]Carp
Fishmeal	45	27	12	6
Fish hydrolysates	5			
Blood meal	5			
Squid meal		3		
Shrimp bran		10		
Yeast	5	5		
Soybean meal	10	20	46	32
Peanut meal	10	20		
Rapeseed meal				40
Corn meal			3.5	8
Low grade wheat flour	13			11.5
Wheat middlings			30	
Wheat gluten meal		10		
Vitamin mix	0.5	1.0	1.0	1.0
Mineral mix	0.5	0.5	0.5	0.5
Lecithin		1.5		
Fish oil	5	2		
Vegetable oil			3.6	
Dicalcium phosphate	1		1.4	
Binder				1.0
Proximate composition (%)				
Crude protein	45.0	40.0	28.6	

Source: [1,2]Jin Haili Feed Co. Ltd, [3]You Yang Feed Co. Ltd, [4]Ying Hui Feed Co. Ltd (pers. comm.)

TABLE 31
Practical feed formulation for fleshy prawn, *Penaeus chinensis*

Ingredients	Ingredient composition (% dry matter)		
	Juvenile	Middle stage	Adult
Fishmeal	27	25	25
Soybean meal	40	40	40
Yeast	5	7	6.5
Shrimp bran*	10	10	12
Squad meal	3	3	1.5
Fish oil	2	2	2
Wheat gluten meal	10	10	10
Lecithin	1.5	1.5	1.5
Vitamin mix	1	1	1
Mineral mix	0.5	0.5	0.5
Approximate cost (US$/tonne)	470	460	450

*by-product from shrimp processing industry.

Source: Yellow Sea Fisheries Research Institute Feed Company, Qingdao, Shandong Province (pers. comm.)

TABLE 32
Practical feed formulation for giant freshwater prawn, *Macrobrachium rosenbergii*

Ingredient (%)	Ingredient composition (% dry matter)		
	Juvenile	Early growout	Late growout
Wheat bran	0	7.85	9.35
Low grade wheat flour	14.35	14.5	18.0
Soybean cake	32.0	23.2	22.5
Rape seed cake	15.2	22.0	21.6
Fishmeal	33.8	22.5	17.5
Coarse fishmeal	0	5.3	6.0
Shell meal	1.0	1.0	1.6
Binder	1.2	1.2	1.0
Moult promoting agent	0.2	0.2	0.2
Growth and immune enhancing additive mix	1.25	1.25	1.25
Coarse powder*	1.0	1.0	1.0
Average cost (US$/tonne)	850–1000	600	

*Mineral powder to improve pelleting and ingredient mixing

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 33
Practical feed formulation for oriental river prawn, *Macrobrachium nipponense*

Ingredient	Ingredient composition (% dry matter)		
	Juvenile	Early growout	Late growout
Wheat bran	-	6.95	10.0
Low grade wheat flour	19.25	18.5	15.75
Soybean cake	29.4	21.0	19.5
Rape seed cake	16.0	20.6	26.0
Fishmeal	23.3	19.0	11.3
Coarse fishmeal	5.4	6.5	4.2
Shell meal	3.2	3.8	4.8
Binder	1.2	1.2	1.0
Moult inducing agent	0.2	0.2	0.2
Growth and immune enhancing additive mix	1.25	1.25	1.25
Coarse powder*	1.0	1.0	1.0
Approximate cost (US$/tonne)	500	400	350

*Mineral powder to improve pelleting and ingredient mixing

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 34
Practical feed formulation for Chinese river crab

Ingredient	Ingredient composition (% dry matter)	
	Juvenile	Adult
Wheat bran	4.75	8.5.5
Wheat flour	13.5	17.5
Soybean cake	28.0	22.0
Rape seed cake	15.0	20.0
Fishmeal	26.0	20.0
Coarse fishmeal	6.0	4.5
Shell meal	3.1	4.0
Binder	1.2	1.0
Moult promoting agent	0.2	0.2
Growth and immune enhancing additive mix	1.25	1.25
Coarse powder*	1.0	1.0
Approximate cost (US$/tonne)	500	400

*Mineral powder to improve pelleting and ingredient mixing

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

3.5 Feed preparation/manufacturing techniques

Farm-made feeds are commonly used in many kinds of aquaculture practices in China, especially in extensive and semi-intensive aquaculture systems. It is estimated that farm-made feeds account for about 40 percent of the country's aquaculture production and the remaining 60 percent are accounted for by natural feeds and by commercially manufactured feeds. This provides some measure of the importance of farm-made feeds. Although the use of commercially manufactured feeds is becoming more popular, farm-made feeds or feeds supplied by small producers are likely to continue to play a very important role in aquaculture in China for a long time to come.

Farm-made feeds have distinct advantages in that they are normally made from locally available ingredients, although this also has serious shortcomings. Many farm-made feeds are unbalanced and are presented in an unsuitable form, which usually results in poor ingestion, nutrient utilization, reduced production efficiency and deterioration of the culture environment. Moreover, due to limited on-farm storage facilities ingredients are not always properly stored, leading to rancidity and mould formation. Using such ingredients in feeds affects the growth and the health of fish.

Various traditional and recently improved techniques are used for the preparation and manufacturing of aquafeeds to enhance quality and water stability. Most feed ingredients are ground to a required particle size and mixing is normally carried out using specialized equipment that meet required mixing standards. Wheat and potato starch are generally used as binders to improve water stability, although special binders may also be used. After compounding the feed the mixture is normally steamed and if required this is done under pressure, particularly in the process of manufacturing floating feeds. Steaming (or cooking as practised by farmers) is very important for binding the feed and for improved nutrient utilization.

Many feed companies sell premixed formulations that are used by farmers either as is or are mixed with other ingredients such as trash fish and then processed into a suitable form. Micronutrient premixes are commercially available in China. In recent years, many special feed additives have been developed. These provide additional properties, e.g. a moult stimulating agent that has been developed for crustaceans. Immuno-stimulants are popularly used in feeds for species that are susceptible to diseases. Presently used immuno-stimulants include Chinese herb extracts and various polysaccharides. Growth enhancement agents are also used in aquafeeds for certain species.

FIGURE 15
Chopped trash fish for making compound feed for Chinese river crab, Suzhou city, Jiangsu province

FIGURE 16
Cooking of feed ingredient for preparation of farm-made feed, Dongping County, Shandong province

FIGURE 17
Commercial dry pellet used for giant freshwater prawn, Gaoyou city, Jiangsu Province

Various techniques are used to improve nutrient utilization of farm-made aquafeeds. Many feed stuffs such as trash fish and pumpkin are chopped (Figure 15) to make them more palatable. Trash fish and mussel meat (frozen or fresh) is minced, particularly for the early stage rearing of fish, shrimp/prawns and crabs. Minced fish is sometimes mixed with other feed ingredients and minced fish is also commonly used in the preparation of moist pellets or paste feeds.

Cooking is a commonly used method to improve the biological quality of certain feed stuffs, especially maize, barley and pumpkin (Figure 16). Cooked feed stuffs are often mixed with other ingredients such as trash fish.

Molluscs such as snails and clams are commonly used as feeds for crustaceans and some fish species such as black carp. The shells are usually crushed by special crushing/grinding machines prior to feed application. This process is often omitted for fish that are able to crush the shell without difficulty.

Many ingredients are ground to a fine powder for nursery operations and growout. The most typical example is grinding soybean or soybean cake to make soybean milk or a granular paste for nursery operations for several fish species. Grain feedstuffs (e.g. maize, barley, wheat bran, soybean/soybean cake) are usually soaked in water before they are fed to the fish or soaked and cooked to improve feed utilization.

The practice of germinating certain grains before application as feeds is most commonly used to meet the special requirement of certain species, e.g. germinated barley sprouts are fed to grass carp broodstock in early spring.

3.6 Feed presentation methods

Feed presentation methods in China are as diverse as the sector itself and vary with species, systems and the level of intensity. Some of the presentation methods are shown in Figures 18–23.

Commercially manufactured feeds are applied in the form of dry pellet (sinking or floating) or moist pastes (such as for eel) (Figure 17). In recent years, the use of floating pellets in intensive culture systems has become more popular. This is mainly because waste and environmental impacts are minimised and nutrient utilization is optimized.

Farm-made feeds are presented in different forms. Some feed stuffs are presented in their original form, such as aquatic weeds, terrestrial grasses and vegetables (Figure 18). Alternatively the ingredients are mixed and processed prior to feeding (Figures 20–22). Moist pellets are also used on some relatively large farms. The extruded moist pellets are usually kept at low temperatures before use. Live food fish are also used for some of the highly carnivorous species such as Mandarin fish. Live food fish such as mud carp and juvenile wuchang bream are either produced in the same waterbody or supplied to the target fish on a regular basis.

FIGURE 18
Green fodder grown on pond dyke for herbivorous fish, Gaoyou city, Jiangsu province

FIGURE 19
Trash fish used as feed for marine fish, Shandong province

COURTESY OF LIANG MENGQUING

FIGURE 20
Cooked maize used as feed for Chinese river crab, Suzhou city, Jiangsu province

FIGURE 21
Paste feed for intensive culture of eel

COURTESY OF HE YIJING

Feed particle size varies according to the requirements of the life history stage or the species. Table 35 lists pellet sizes for some of the important aquaculture species at different stages.

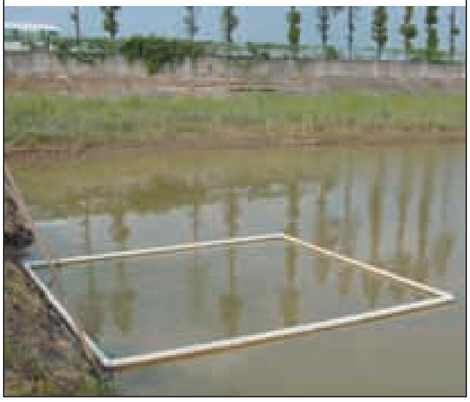
TABLE 35
Feed pellet size for some important aquaculture species in China

Species	Stage	Size standard	
		Diameter (mm)	Length (mm)
Common carp/ crucian carp	Fingerling	1.0–2.0	2.0–4.0
	Growout	2.0–4.0	4.0–7.0
Wuchang bream/ grass carp	Fingerling	1.0–2.0	2.0–4.0
	Growout	2.0–4.0	4.0–7.0
Nile tilapia	Fingerling	1.0–2.0	2.0–4.0
	Growout	2.0–4.0	4.0–7.0
Chinese river crab	Juvenile	1.0–2.0	2.0–3.0
	Growout	2.0–5.0	4.0–7.0
Oriental river prawn	Juvenile (crumble)	0.3–1.0	0.3–1.0
	Juvenile (pellet)	0.5–1.5	1.5–3.0
	Middle stage	1.0–2.0	2.0–5.0
	Adult	1.8–2.5	4.0–7.0
Giant freshwater prawn	Juvenile (crumble)	0.3–1.0	0.3–1.0
	Juvenile (pellet)	0.5–1.5	1.5–3.0
	Middle stage	1.0–2.0	2.0–5.0
	Adult	1.8–2.5	4.0–7.0
Pacific white shrimp	Juvenile (crumble)	0.3–1.0	0.3–1.0
	Juvenile (pellet)	0.5–1.5	1.5–3.0
	Middle stage	1.2–2.0	3.0–4.0
	Adult	1.0–2.0	2.0–5.0
Swimming crab	Growout	4.8–5.6	12–19

Source: various feed manufacturers (pers. comm.)

FIGURE 22
Preparation of semi-moist feed for crab by mixing cooked maize and chopped fish, Suzhou city, Jiangsu province

FIGURE 23
Floating feeding frame for application of green fodder in a pond, Gaoyou city, Jiangsu province



The feeding rate is very much dependent on the type of feed, water temperature and culture stage of the stock. Dry pellets are normally fed to finfish at 2–5 percent of body weight per day. Feeding rates for shrimp are much higher and usually range from 4–8 percent of body weight, while the feeding rate of herbivorous fish with green fodder can be as high as 10–20 percent of body weight per day. Daily rations are controlled through different means in the various culture practices. Although the daily ration is generally determined according to average fish weight and temperature, the actual amount is often adjusted according to the feeding behaviour and intensity of the fish. This is often assessed by checking the feed left over in feeding areas or on feed trays at a certain time after feeding. A commonly used feeding schedule for Nile tilapia is illustrated in Table 36, which also shows that ration is determined by the level of intensity.

Feeding frequency is dependent on the feeding habit of the species and the feed application method. In shrimp/prawn culture, animals are fed 4–6 times daily in the early stage of culture and later reduced to 3–4 times per day. If manual feeding is practiced then fish are normally fed 2–3 times per day. If automatic feeders are used then fish are normally fed 4–6 times a day. Frequent feeding can improve feed utilization.

Several feed application methods are illustrated in Figures 23–27. A floating frame is usually used in ponds for feeding with aquatic weeds, terrestrial grasses or vegetable leaves (Figure 23). The frames are commonly made of bamboo and confine the floating feed. Residues and uneaten material are concentrated on the bottom, under the frame, which facilitates easy removal. Feeding trays are also traditionally used for the application of sinking pellets and are also useful to monitor feeding intensity, adjusting the daily ration and to monitor fish health Figure 24).

TABLE 36
Feeding recommendations for different size classes of tilapia under different farming conditions

Fish weight (g)	Feed particle size (mm)	Feeding rate (% wet body weight)		Feeding frequency (time/day)
		Semi-intensive (<20 000/ha)	Intensive (>20 000/ha)	
<1	<0.5	30–10	-	To satiation
1–5	0.5–1.0	10–6	-	6
5–20	1.0–2.0	6–4	-	4
20–100	3.2	4–3	-	4
100–250	3.2–4.6	3	-	3
250–500	4.6	3–2	2–1.5	3
>500	4.6	2–1.5	1.5–1.3	3–2

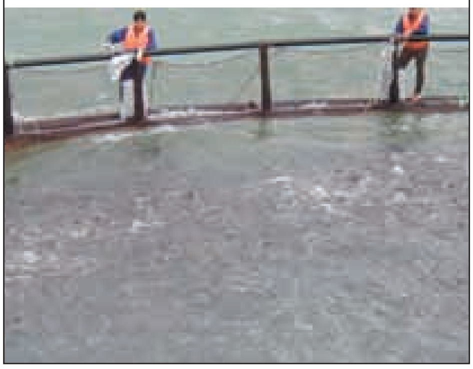
Source: Yellow Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences (pers. comm.)

FIGURE 24
Feeding tray used for sinking feeds in a semi-intensive fish pond, Suzhou city, Jiangsu province

FIGURE 25
Semi-automatic feeder used in intensive fish pond, Gaoyou city, Jiangsu province

FIGURE 26
Feeding by broadcasting for tilapia in freshwater cage culture, Hepu County, Guangxi Autonomous Region

FIGURE 27
Broadcasting of trash fish in marine cages, Shandong province



COURTESY OF LIANG MENGQUING

Feeding shelves are usually used in indoor re-circulating systems for application of dough or paste feeds, e.g. for eels. Semi-automatic and automatic feeders for dry sinking or floating pellets are now commonly used in intensive pond culture and cage culture (Figure 25). The feeders are set to deliver a certain amount of feed at pre-determined times. Broadcasting of feed over the water surface is a common feeding method used in intensive shrimp and prawn culture and during the early stages of fish nursery operations (Figures 26 and 27). It is performed by hand either from the pond dyke or from a boat.

4. THE DEVELOPMENT OF AUQAFEED INDUSTRIES IN CHINA

4.1 Background and historical development

China is currently the world's largest producer of industrially compounded aquafeeds. The bulk of the feed is manufactured for freshwater cyprinids. It is estimated that 40–45 percent of farmed fish in China are fed on industrially manufactured compound aquafeeds and about 8.0 million tonnes of commercial aquafeeds are produced annually. Currently, there are over 360 large and medium scale aquaculture feed manufacturers with an annual production of about 2.7 million tonnes. There are also a large number of small aquafeed mills that produce feeds on demand. Local and international research results provide the basic reference points for formulating commercial aquafeeds. Aquafeed technologies were introduced from Taiwan Province of China, Europe and the United States of America. Presently, aquafeed machinery is manufactured in China.

The development of China's animal feed industry started in the late 1970's. In May 1984, the State Council promulgated the "1984–2000 Outline of China's Feed Industry Development". This plan resulted in China's feed industry growing from practically nothing in 1975 to one of the worlds largest within two decades. The number of mills expanded to over 14 000 in 1985. State owned and managed mills constituted over 60 percent of all feed mills at the end of the 1980's. However, this has changed and most are now owned and operated by the private sector or by public/private joint venture companies. In 1976 the total annual output of compound animal feeds was 0.6 million tonnes. By 2002 production had increased to 56 million tonnes and by 2004 to 93 million tonnes.

Since the late 1980's the demand for compound aquafeeds has increased rapidly. At present there are more than 10 000 large, medium and small aquafeed mills to include that produce different feeds and additives. Most of the feed mills are located in coastal areas such as Guangdong, Fujian, Hainan, Guangxi, Zhejiang, Shandong, Liaoning, Shanghai and Tianjin and the feed output of these provinces account for more than 50 percent of total aquafeed production. Feed mills producing feeds for common freshwater fishes are located mainly in Sichuan province. By 2004, China produced over 8 million tonnes of compounded aquafeeds, which then accounted for 8.6 percent of total compound animal feed production. The aquafeed industry is the fastest expanding agricultural industry in China and is currently growing at over 30 percent per annum. The industry is also becoming more efficient as old and inefficient mills are closed and new mills are opened.

During the 1980s the Customs Bureau of China removed import levies on feed milling equipment and reduced the levies on many feedstuffs. By 1990 there were over 270 factories that manufactured feed milling equipment. The reduction in levies on feed stuffs led to the formation of joint ventures and the entry of foreign owned feed manufacturing firms from Thailand, United States of America, Japan, United Kingdom, Hong Kong and Taiwan Province of China. These changes have significantly influenced the industry by introducing new milling techniques, feed formulations, management methods and marketing practices. The competition within the aquafeed industry has also made the sector more efficient. Initially, aquafeeds were produced as a special feed line in existing livestock feed mills. This has obviously changed and extruded and floating aquafeeds made by specialist aquafeed mills have been commercially available since 1996. While compound feeds were initially only fed to high value export species such as marine shrimp, producers are expanding the use of compound feeds for other species as well.

Aquafeeds are manufactured in different forms and the nutrient composition depends on the species and stage of growth. Feed cost varies with quantity, quality and type of product (sinking or floating pellets, powder for soft feeds or microparticulate feeds for fry). At this juncture the bulk of the microparticulate feeds used in marine finfish aquaculture is imported. There are only five aquafeed mills that produce microparticulate diets for marine fish and output does not meet the demand.

4.2 Quality assurance and feed standard

The sharp increase in demand for aquafeeds in the 1980s and 1990s resulted in the shortage of feed ingredients and poor feed quality. Poorly formulated feeds and or improper manufacturing processes also resulted in low digestibility and poor water stability. Furthermore, the use of feed additives such as growth promoters, hormones and antibiotics was uncontrolled. To resolve these problems the Ministry of Agriculture now supports the National Center for Quality Supervision and Test of Aquatic Products and the aquafeed industry associations in feed quality assurance.

Under the new regulations, feed mills must secure a license before they are allowed to operate and must register the nutritional composition and value of their formulations.

Feed processing plants are inspected by the feed industry associations and by the National Center for Quality Supervision and Test of Aquatic Products. Sanitary tests are conducted and mills are inspected to ensure proper storage and use of raw materials and hygiene during the manufacturing process. Feeds are tested randomly to ensure that they meet the stipulated minimum and advertised standards. Products are also tested for antibiotic levels and hormone residues. Some feed standards are shown in Tables 37 to 40. To facilitate inspection and quality control of aquafeeds, national, provincial and district centres of feed quality control have also been established.

TABLE 37
Feed specification for fleshy prawn (*Penaeus chinensis*)

Number	Feed type/ class	Shrimp size (cm)	Pellet diameter (mm)	Pellet length (mm)
01	Starter	1.0–3.0	0.5–1.5	1.5–3.0
02	Grower	3.1–8.0	1.2–2.0	2.0–5.0
03	Finisher	>8.0	1.8–2.5	4.0–8.0

Source: MOA (2002)

TABLE 38
Guaranteed analysis of feed for fleshy prawn (*Penaeus chinensis*)

Parameters			Index
Pellet diameter	≤	0.425 mm	3
		0.250 mm	20
Degree of homogenity of mixing	≤		10
Water stability (leaching rate) (%)	≤		12
Moisture (%)	≤		11
pH			5.0–8.5
Crude protein (%)	≥		38
Crude lipid (%)			3–8
Crude fibre (%)	≤		5
Ash (%)	≤		16

Source: MOA (2002)

TABLE 39
Guaranteed analysis (%) of feed for flounder

Parameters		Starter pellet	Juvenile	Adult
Fish length (cm)		<5.0	5.0–-15.0	>15.0
Leaching rate (%)	≤	4.0	4.0	4.0
Crude protein (%)	≥	50	45	40
Crude lipid (%)	≥	6.5	5.5	4.5
Crude fibre (%)	≤	1	2	3
Ash (%)	≤	15	16	16
Moisture (%)	≤	10	10	10
Ca (%)	≤	4	4	4
P (%)	≥	1.5	1.5	1.5

Source: MOA (2002)

TABLE 40
Technical specifications for formulated feed of eel

Feed grade		White eel	Black eel	Juvenile	Growout
Fish size, weight (g)		<0.5	0.5–2.0	2.1–15.0	>15
Physical and chemical characteristics (%)					
Mesh size (μm)	≤	200		250	
Degree of homogenity of mixing	≤	5.0	8.0	10.0	10.0
Leaching rate (%)	≤	4.0			
Crude protein (%)	≥	52.0	47.0	46.0	45.0
Crude lipid (%)	≥	3.0			
Fibre (%)	≤	0.8		1.0	
Moisture (%)	≤	10			
Ash (%)	≤	18			
Ca (%)	≤	4.6			
P (%)	≤	1.5			
Sand (%)	≤	2.0			
Sensory characteristic					
General appearances		Uniform color, without mould, deterioration, blocking and insects growth			
Visco-elasticity		Good extensibility after stirring	Good extensibility and visco-elasticity after stirring		

Source: MOA (2002)

TABLE 41
Fishmeal imports and exports for 1995–2004 (tonnes)

Year	Export	Import	Consumption
1995	3 367	690 050	686 683
1996	778	882 476	881 698
1997	1 488	985 234	983 746
1998	1 474	416 188	414 715
1999	1 308	631 271	629 963
2000	1 718	1 185 713	1 183 994
2001	1 690	901 696	900 007
2002	3 767	958 151	954 384
2003	4 160	800 251	796 090
2004	5 026	1 123 082	1 118 056

4.3 Exports and imports of feed ingredients and additives

As the aquaculture industry expanded imports of feed ingredients, mainly fishmeal, soybean meal and amino acids increased proportionally. Export and import volumes of fishmeal for 1995–2004 and soybean and three amino acids (glutamine, lysine and methionine) for 2000–2004 are shown in Tables 41 and 42. To promote the development of the aquaculture feed industry, relatively low tariffs are levied on the major imported raw materials in China.

TABLE 42
Soybean and amino acid imports and exports for 2000 to 2004 (tonnes)

Year	Soybean		Glutamic acid		Lysine		Methionine	
	Export	Import	Export	Import	Export	Import	Export	Import
2000	215 265	10 419 368						
2001	261 177	13 939 933	17 607	24 460	782	73 601	275	57 674
2002	305 365	11 315 348	37 167	14 757	974	81 351	186	53 805
2003	294 790	20 741 111	44 135	5 661	8196	75 488	263	72 867
2004	348 648	20 229 940	34 101	2 865	22954	76 475	454	85 819

For example, in 1999 import tariffs on fishmeal intended for aquafeeds was 3 percent, compared to 30 percent for aquatic products imported for human consumption. Similarly, import duties for soybean meal used for feed production were 40 percent, compared to 114 percent for soybean products imported for other uses. The import duty on fish oil is 30 percent. The preferential duties on important protein sources for animal feeds have had a positive effect on the availability and quality of feeds for aquaculture as well as for animal husbandry.

Presently China imports about 1.2 million tonnes of fishmeal per year, mainly from Peru, Chile and Russia to sustain its feed industry. About 75 percent of the imported fishmeal is used for aquafeeds. The annual local soybean production is about 15.5–17.55 million tonnes and China imports more than 20 million tonnes of soybean from the United States of America and Canada.

Additives such as vitamin and mineral premixes, stable vitamins, amino acids, chelated trace elements, mixed enzymes, phytase, probiotics, prebiotics, immunity stimulants, attractants, antioxidants and binders are ether locally produced or imported. Generally, most of the additives are produced in China although amino acids, such as glutamic acid, lysine, methionine and some vitamins are imported.

4.4 Shrimp feed industry

Rapid developments in the shrimp feed industry have contributed to the substantive harvests in recent years, particularly in the southern coastal regions of China. Shrimp farming in China was initially facilitated by breakthroughs in larval rearing technologies and latterly through the development of appropriate feeds. Early rearing stages depend on single cell algae (*Phaeodactylum tricornutum, Nitzschia closterium, Chaetoceros muelleri, Platymonas* spp. among others) and minced egg yolk and soybean milk are also used for larval rearing, followed by rotifers and *Artemia* nauplii. Most hatcheries are equipped with live feed culture facilities. Dried and powdered *Spirulina* is used in some hatcheries to substitute or supplement live microalgae. Other feeds, such as minced clam meat and yeast powder are also used separately or mixed. Presently, microparticulate and microencapsulated feeds are widely used in Chinese shrimp hatcheries.

Before the advent of compound feeds shrimp were fed on fishery by-products, such as low-value fresh trash fish, invertebrates and shellfish. These were abundant in the intertidal zone and shallow coastal waters and where fed either directly or after being chopped or crushed. Presently, all shrimp farmers use compound feeds with food conversion ratios of 1.2–1.6:1.

4.5 Freshwater fish feed industry

Approximately 70 percent of all aquafeed production in China is used for pond culture of grass carp, common carp, crucian carp an Nile tilapia. Many other feedstuffs such as rice bran, rapeseed meal, peanut meal, soybean meal and silkworm pupae are also used in earthen pond systems in combination with organic or inorganic fertilization. However, it is estimated that only 30 percent of carp are now reared on "traditional" feeds. As a consequence of the switch to compound feeds the carp production cycles are 20–25 percent shorter than they were 10 years ago and average FRCs are 1.5:1. Given the relatively low value of carp, feed formulation has become of pivotal importance in this highly competitive sector. The current carp growout formulations contain a variety of ingredients such as fishmeal, peanut meal, soybean meal, rapeseed meal and cotton seed meal. To remain competitive the feed manufacturing sector is very aware of the need to be flexible and to further reduce the fishmeal component of carp feeds. This will ensure the continued and long term sustainability of the sector.

4.6 The marine fish feed industry

Compared with freshwater fish production total marine fish aquaculture production is relatively small, but all are high value species. Marine fish in cages and in ponds are fed mainly on trash fish, farm-made feeds and extruded pellets, while large-scale industrial systems exclusively use extruded pellets. Farm-made feeds are made from commercial feed premixes (60–70 percent) that is mixed with trash fish (30–40 percent) to form soft pellet or dough. The moisture content of soft feeds is 25–30 percent.

As mentioned above, the type of feed is largely determined by the culture system. For example, since the 1960s aquaculture of olive flounder expanded rapidly and the species is now farmed intensively in land based flow-through systems, in cages as well as in ponds. In flow-through systems and to some extent in cages the fish are fed on pellets, while farm-made feeds consisting of premixed feed powders and a high proportion of trash fish are predominantly used in cages and in ponds. The high cost and reduced availability of trash fish is becoming problematic and the environmental impacts of using trash fish are well recognised and hence it is important to develop species specific feeds for the intensive production of marine fish. The detailed nutritional requirements of olive flounder have only recently been defined (Lei, 2005) and these findings provide the basis upon which a specific extruded flounder feed can be developed. Despite the absence of a specific formulated feed for flounder, over 40 percent of flounder is produced using formulated feeds. Olive flounder readily accept dry formulated feeds and FCRs of 1.2:1 have already been achieved. The development of specific formulated feeds will go a long way to ensure the future sustainability of the marine fish farming sector in China.

As with flounder, the farming of large yellow croaker (*Pseudosciaena crocea*), mainly in cages, is also largely dependent on the use of trash fish based farm-made feeds. Recent studies have shown that the use of trash fish affects flesh quality in yellow croaker. The basic nutritional requirements of large yellow croaker are known (Duan *et al.*, 2001) and an extruded diet for this species has been developed and is now widely used, with FCRs of 1.5:1. These two examples illustrate the changes that are occurring in the feeding of marine fish in China.

5. PROBLEMS AND CONSTRAINTS OF AQUACULTURE FEEDS AND FEEDINGS

The main trends in aquaculture development in China over the past two decades have been described in the preceding sections and can briefly be summarized as follows:

- There is a general trend towards intensification of farming systems. This is driven by the need to limit resource use and simultaneously to maximize production and return on investment.
- There is a clear trend towards greater species diversification. This is in response to changes in consumer preferences and the farmers' pursuance of better margins. Most of the species that have recently been introduced into aquaculture are generally dependent on artificial feeds.
- These trends have led to the increasing dependence on and demand for formulated feeds.

The overall growth of the sector and the trends described above have given rise to several major problems and constraints and these are:

- Availability and accessibility of aquaculture feed ingredients will become a major constraint, particularly in view of expected increases in production and the increasing use of artificial feeds.
- Accessibility to aquafeed ingredients (e.g. fishmeal, trash fish, soybeans) may become a limiting factor under certain circumstances.
- Reduced integration of fish with animal husbandry may create problems with respect to the availability of organic fertilizers.
- Because of competition for feed resources, aquaculture may become less competitive in relation to other sectors with higher economic returns.
- Poor quality farm-made feeds may affect feed utilization and efficiency.
- Improper feed application affects feed utilization and profit margins and has negative environmental impacts.
- Small and medium-scale farmers are affected by the increasing dominance of feed manufacturing companies and suppliers.

If these problems and constraints are not appropriately addressed they may negatively impact on the growth of the aquaculture sector and its sustainable development.

5.1 Availability and accessibility of feeds, feed ingredients and fertilizers

The most pressing constraint facing Chinese aquaculture is the future availability of and accessibility to feed ingredients. This constraint is fuelled by two major factors. First, while the growth rate of Chinese aquaculture has slowed down in recent years it is inevitable that production will and has to increase significantly in the coming years. According to the national fisheries development plan, by 2010 the per capita availability of aquatic products is expected to reach 44 kg. To meet this target, total fisheries production must reach 57.2 million tonnes, an increase of 8 million tonnes over the 2004 national production figure. Considering the stagnant or even slightly declining catches from capture fisheries, the increasing demand for aquatic products can only be met by aquaculture. For various reasons as outlined above, aquaculture will become more dependent on artificial feeds hence increasing the demand for core ingredients. By 2010, it is estimated that the demand for commercially produced aquafeeds will be 15–20 million tonnes, excluding farm-made aquafeeds. This is a 46–60 percent increase over the 2004/05 production of 8 million tonnes.

Secondly, China has a population of 1.3 billion people, increasing by approximately 17 million annually. It is an onerous task for China to meet the basic grain demands of its increasing population. It is also unlikely that the increasing demand for aquafeed ingredients can be met by national agriculture and fisheries production capacity. In addition, competition for feed ingredients of plant origin from the expanding animal husbandry sector will intensify and this will put further pressure on the supply side.

The future supply of fishmeal for the Chinese aquaculture industry will become increasingly problematic. In recent years the inclusion rate of fishmeal in aquafeeds has increased substantially to improve feed efficiency. This, coupled with the increased production levels of shrimp, prawns and fish, all of which have a high protein demand of animal origin has increased the demand for fishmeal significantly. National production of fishmeal is limited and most of the fishmeal used in China is imported. Presently, world fishmeal production is maintained at around six million tonnes. The increasing demand for fishmeal by China will therefore have a major and very significant impact on the balance of demand and supply in the world market.

Traditional aquaculture practices were closely linked to animal husbandry. Hence organic fertilizer was a very important input in production systems. This was convenient and practical in that it provided a means of increasing farm production through recycling of biological wastes. In recent years aquaculture has become more isolated from animal husbandry for various reasons. Most importantly the poor economic returns from improperly managed animal rearing activities have made these practices unviable. Moreover, small-scale animal rearing is gradually being replaced by large-scale, industrial operations. This reduces the traditional linkage between aquaculture and animal husbandry and also impacts on the supply of organic fertilizers. The inconvenience and additional transport costs in acquiring adequate quantities of manure is to now limiting the use of organic fertilizers in fish culture.

5.2 Economic and social constraints of feed resource use

Due to the rapid expansion of the animal feed industry, including the aquafeed industry, the increase in demand for feed ingredients has pushed market prices steadily upwards. According to data released by the Ministry of Agriculture, between 2002 and 2004 the price of maize increased by nearly 30 percent, soybean meal price by about 90 percent (up to US$360/tonne in 2004) and fishmeal by 10–15 percent in the same period. These significant price increases over a relatively short time period have impacted on the economic returns of farmers as well as feed manufacturers.

Despite concerted efforts by all role players to improve the quality of aquafeeds and their application, utilization efficiency is far from satisfactory and this results in excessive discharge of nutrients into the environment. The increasing use of commercial feeds in aquaculture has also resulted in greater public concern on the pollution of aquatic environments by aquaculture.

Improving the quality of aquafeeds to achieve greater feed efficiency, higher returns and reduced environmental impacts has become an urgent issue for the sustainable development of aquaculture in the country. The major challenge lies in improving feed quality without increasing costs. Major technical breakthroughs in the nutrition of cultured animals and feed manufacturing technology are, therefore, urgently needed.

5.3 Use of commercially manufactured pellet feeds by small and medium-scale aquaculture

The recent trend towards greater use of manufactured feeds has advantages and disadvantages. The advantages include greater convenience and offer farmers a greater choice with respect to species selection and also improved production efficiency and yield. On the other hand, the disadvantages of industrially manufactured feeds, especially for small and medium scale farmers, must not be overlooked and these are:

- reduced the usage of locally available resources, which are usually cheaper;
- increasing number of farmers abandoning traditional semi-intensive polyculture systems, which usually and often have sound ecological and economic benefits;

- breacking of the traditional linkage between aquaculture and other agricultural activities such as animal husbandry and horticulture, which promotes recycling of wastes and by-products;
- increasing dependence of farmers on feed manufacturers and retailers influences their production goals and decisions; and
- high input-high output production systems using pelleted feeds increases market risks to the farmers, especially when they are mislead by feed suppliers.

6. RESOURCE AVAILABILITY AND THE EXPANSION OF THE AQUACULTURE INDUSTRY

During the period 1980–1990 the average annual growth rate of aquaculture was around 10 percent and from 1999–2000 it was 11.1 percent. The future expansion of the aquaculture industry in China will largely depend on available resources (feed and fertilizers) and support facilities (science, technology, feedmills and improved life support systems).

6.1 Ingredient requirements

Because of their high nutrient density, formulated aquafeeds are among the most expensive animal feeds in the market. Their high cost is also largely attributable to the liberal use of expensive ingredients such as fishmeal and fish oil. Due to an increasing demand for aquafeeds and overfishing, the demand for fishmeal will exceed supply in the very near future. Hence there is a desperate need to assess and exploit new protein sources to replace fishmeal in artificial feeds as much as possible. This is particularly important for China, which has the largest aquaculture industry in the world but only produces a very limited quantity of fishmeal.

According to the China Fisheries Yearbook (2001) the total aquaculture production of 25.8 million tonnes in 2000 (excluding aquatic plants and seaweeds) consisted of 52.1 percent filter feeders, 26.4 percent omnivorous species, 12.3 percent herbivorous species and 4.5 percent carnivorous species. The production subtotal for omnivorous, herbivorous and carnivorous species therefore amounted to approximately 11.2 million tonnes (Table 43). If all of the former had been produced using compound feeds at a FCR of 1.5:1 then approximately 16.7 million tonnes of artificial feeds would have been required. At present, China has to import about 1.2 million tonnes of fishmeal a year for the animal feed industry and of which, aquafeeds use approximately 70 percent. If the annual production of aquafeeds reaches 16.7 million tonnes as calculated above, then China would need approximately 3.64 million tonnes of fishmeal per annum to sustain its current production of fish and crustaceans (Table 43). The carnivorous species consumed the largest proportion of the available fishmeal (71.1 percent of the total used in aquafeeds), followed by omnivorous species (17.3 percent), and herbivorous species (9.3 percent). In addition, about 4 million tonnes of trash fish are used as feed for marine finfish. To meet this theoretical demand is, quite frankly, impossible. The only way to sustain the required level of growth of aquaculture in China is to exploit new protein sources and reduce the fishmeal inclusion levels in feeds. However, significant reductions in dietary fishmeal inclusion levels will result in reduced feed palatability and production. It is therefore important for science to consider not only the possible essential amino acid imbalances but also to pay particular attention to feed attractants.

In 2004, freshwater fish were the biggest consumers of commercial feeds (accounting for approximately 70 percent of total aquafeed usage), followed by shrimp (10 percent). The main ingredients in freshwater fish and shrimp feeds are soybean meal, peanut meal and rape seed meal and on a combined basis their total inclusion level amounts to about 50 percent In 2003, the total production of common carp, crucian carp, tilapia, wuchang bream, black carp and grass carp was about 9.15 million tonnes. On the basis of a FCR of 1.5:1 these fish consumed an approximate amount of 13.7 million tonnes of feed. Similarly, the production of 1.3 million tonnes of crustaceans in 2003 at a FCR of 1.5:1 would have consumed approximately 2.0 million tonnes of feed. This suggests that about 15.7 million tonnes of feed were consumed by freshwater fish and crustacean alone. However, in 2003 total commercial aquafeed production only amounted to some 7.8 million tonnes. Notwithstanding the fact that marine fish were not considered in this calculation it is clear that there is a substantial gap between the requirement for commercial feeds and actual production.

To predict the future feed requirements of the aquaculture industry we used data provided by the National Feed Industry Office (Table 44). It was calculated that freshwater fish will have the highest requirement and that marine fish species like flatfish, grouper, cobia, large yellow croaker, seabass and shrimp will eventually require substantial amounts of artificial feeds because of increasing production. It is also predicted that trash fish will be gradually replaced by artificial feeds in the coming ten years. At current growth rates the predicted total feed requirement for all sectors by 2015 is approximately 54 million tonnes (Table 44). Because not all fish farmers will be using artificial feeds by 2015 and because FCRs are expected to improve this estimate is considered as the upper maximum, but gives some inkling of the magnitude of the challenges faced by Chinese aquaculture.

To evaluate whether the available raw materials can sustain the requirements for the projected production increases, the feedstuff requirements and available resources are compared. The projected potential annual demand for feed ingredients by the animal feed industry is shown in Table 45, which shows that there will be a 43.2 million tonne shortfall for energy sources and a 25.2 million tonne shortfall for protein sources.

TABLE 43

The potential annual demand of fishmeal for aquaculture feeds in China (based on aquaculture production in 2000)

Feeding habits	Estimated production (million tonnes)	FCR (approx)	Feed production (million tonnes)	% fishmeal in feed	Requirement of fishmeal (million tonnes)
Carnivorous	1.16	1.5	1.74	40	0.70
Omnivorous	6.81	1.5	10.22	25	2.56
Herbivorous	3.17	1.5	4.76	8	0.38
Total	**11.14**		**16.7**		**3.64**

TABLE 44

Predicted production and feed requirement of major aquaculture species by 2015 (million tonnes)

Species	2004	2015	FCR	Feed requirement by 2015
Freshwater aquaculture	18.92	20.0	1.5	30.0
Mariculture	13.17	16.0	1.5	24.0
Total	**32.09**	**36.0**		**54.0**

Source: National Feed Industry Office, MOA, Beijing (pers. comm.)

TABLE 45

Projected potential annual demand of feed resources for animal feeds including aquafeeds by 2015

Source	2015		
	Requirement (million tonnes)	Available resources (million tonnes)	Demand shortfalls (million tonnes)
Cereals/energy sources	320.5	277.3	43.2
Protein sources	50.0	24.8	25.2

Source: National Feed Industry Office, MOA, Beijing (pers. comm.)

6.2 Fertilizer requirement

The role of fertilizers in pond culture has become less important than before, especially during growout. Fertilizers are still needed in extensive and semi-intensive ponds where natural food is required. It is predicted that the total pond surface area will remain relatively constant over the next 10 years and because fertilizer requirements are calculated on the basis of surface area it is predicted that adequate quantities of organic and inorganic fertilizers will be available for the foreseeable future.

7. RECOMMENDATIONS FOR IMPROVED UTILIZATION OF FERTILIZERS AND FEED RESOURCES

Aquaculture has many advantages over other animal production sectors, such as high food conversion efficiencies, low surface area requirements and relatively high economic returns. Aquafeeds, in particular as well as fertilizers are among the most important limiting factors that will affect the expansion and sustainable development of the industry in the future. Greater efficiency in the use of feed and fertilizer resources is therefore required. The industry already faces several problems and constraints and others will emerge with time. Based on the preceding review, it is recommended that the following strategies and policy guidelines be implemented to address the challenges.

7.1 Development of new feed ingredient resources

China is a country with a huge population and relatively limited land resources. Competition for feed ingredients (especially for fishmeal and grains) will no doubt increase in the foreseeable future. Therefore, it is very important to develop new resources for aquafeeds.

In addition to commonly used feed ingredients such as maize, barley, soybean and groundnut cake, China currently produces over 50 million tonnes of rice bran and wheat bran, over 20 million tonnes of residues from distiller and brewery waste and over 30 million tonnes of potato, sweet potato and cassava. With appropriate technologies the use of high quality feed ingredients such as grains and oilseed cakes can be significantly improved. The utilization of plant proteins by aquatic animals is still inefficient, e.g. only 50 and 70 percent of the proteins in rapeseed and soybean cake are utilized. By improving the protein utilization of these ingredients by 20–30 percent would, for example, provide an additional supply of 1 million tonnes of high value ingredients.

In addition, by changing agricultural systems, special feed ingredient crops should be cultivated increase production within the existing constraint of available farm land. For example, growing green fodder on pond dykes and other scattered and unused land areas within farm boundaries can replace commercial feeds for herbivorous species.

7.2 Promote fish farming systems and practices that increase the efficient use of feeds and fertilizers

The Chinese aquaculture sector is characterised by highly diversified culture systems and practices. There is a growing tendency for farmers to abandon traditional and highly efficient aquaculture systems and practices in favour of simpler feed based systems with higher production levels. This is especially the case in relatively well developed areas where the use of fertilizers and locally available resources is decreasing and the use of commercial feeds is increasing. Farmers are not always aware of the fact that these changes have, in many instances, led to reduced feed efficiency and increased production costs. A typical example is that the FCR in super intensive shrimp farming systems is usually 20 and 10 percent higher than under semi-intensive and intensive farming conditions, respectively.

The adoption of aquaculture systems and practices with optimum feed and fertilizer utilization efficiency is a strategy that should be vigorously promoted. Practices that should be promoted include semi-intensive, pond based multi-species polyculture, integrated aquaculture in paddy fields, integrated fish farming (fish-crop-animal) and semi-intensive polyculture of shrimp, finfish, seaweed and molluscs in brackish-water ponds. Where monoculture is undertaken, farmers should be encouraged to use semi-intensive instead of intensive or super-intensive practices.

7.3 Promoting improved management practices

Improving the culture environment can play a significant role in improving feed utilization. For example, the FCR of grass carp under pond culture conditions at optimum temperatures increases 1.34 fold at DO levels below 3.4 mg/l compared with DO above 3.5 mg/l and feed intake is reduced by 35 percent compared with DO levels above 7 mg/l (source: http://www.china-fisheries.com/zhuanlan/displaytech.asp?sort=feed&id=3313, 2004).

Some new approaches have recently been adopted, such as the use of beneficial micro-organisms and aerators. However, some traditional and very effective methods, such as pond draining, sun-drying of the substratum, removal of excessive silt and clearing before restocking have been abandoned by many farmers due to various reasons. It is very important to encourage farmers to retain traditional pond management techniques to maintain good culture environments, especially with respect to the improvement of pond bottom conditions. In addition, other modern techniques and equipment should be more efficiently used to maintain water quality above certain standard thresholds. For example, aerators should not only be used in emergencies when DO levels are critically low but should be used to improve oxygen distribution when surface oxygen levels are high. The relatively higher cost of power is compensated for by the comprehensive benefits generated by improved feed utilization.

An approach that is currently receiving attention is the biological treatment of intensive aquaculture effluents that will enable water re-use. This may have significant future implications.

7.4 Strengthen scientific research and technology development

By improving feed manufacturing technologies and feed application techniques, it is possible to maximise the utilization of available feed resources. The following research and development priorities have been identified.

Comprehensive nutrition research

The industrial aquafeed industry in China is relatively new and is a sector that has to provide appropriate products for a hugely diverse and rapidly growing production sector. The absence of detailed research on the nutritional requirements of culture species imposes enormous challenges on the industry. Research is required on the nutritional requirements of cultured species at different stages of ontogeny and under different environmental and culture systems and practices. In particular, it is important to understand the utilization efficiency of different ingredients at different life history stages of the species, such that the most appropriate feeds can be formulated. Moreover, there is a need to better understand the feeding behaviour of fish and shrimp species under different culture practices and systems and ontogenetic stages.

Development and adoption of technology to improve the utilization of different feed ingredients

Feed manufacturing technologies have to be developed to improve nutrient utilization of different feed ingredients. Advanced processing technologies can significantly improve the acceptability and digestibility of feeds by altering the internal structure and providing appropriate physical features to the feed. These need to be developed.

Research on feed additives to improve feed utilization must also be promoted. In particular this research should focus on enzymes, essential amino acid, fatty acids, vitamins, minerals, immuno-stimulants and growth enhancing agents.

Although feed manufacturers produce over 100 different types of feeds for cultured species at different culture stages, the formulations are based on limited scientific research. In most instances the available feeds are simple adaptations of the formulations for similar species with minor modifications. Hence, more resources should be invested by both the public and the private sector to strengthen the scientific basis of feed formulation and to develop new and innovative ingredient processing technologies

7.5 Improve on-farm feed application technologies

When aquafeeds are applied under certain conditions, the utilization of the feed is highly dependent on the application schedules and methods. While less wasteful feeding methods have been adopted by farmers in recent years, their feeding schedules are largely based on tradition and lack a scientific basis. Hence feeding rates, frequencies and feeding times vary greatly among and between farms and is manifest in highly variable production levels. There is a very real need to establish standard feeding schedules for various species at various life history stages under specific culture practices and environmental conditions.

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APPENDIX

Appendix A. Aquaculture species in China

A.1. List of major aquaculture species in China

Common name	Scientific name
Amberjacks	*Seriola spp*
Bighead carp	*Aristichthys nobilis*
Black carp	*Mylopharyngodon piceus*
Black tiger shrimp	*Penaeus monodon*
Catfish	*Clarias leather*
Channel catfish	*Ictalurus punctatus*
Chinese long-snout catfish	*Leiocassis longirostris*
Chinese river crab/Chinese mitten-handed crab	*Eriocheir sinensis*
Cobia	*Rachycentron canadum*
Common carp	*Cyprinus carpio*
Crucian carp	*Carassius carassius*
Estuarine tapertail anchovy	*Coilia ectenes*
Fleshy prawn	*Penaeus chinensis*
Giant freshwater prawn/giant river prawn	*Macrobrachium rosenbergii*
Goldfish	*Carassius auratus auratus*
Grass carp/white amur	*Ctenopharyngodon idella*
Grouper	*Epinephelus spp.*
Japanese eel	*Anguilla japonica*
Japanese shrimp/kuruma prawn	*Penaeus japonicus*
Large yellow croaker	*Pseudosciaena crocea*
Largemouth bass	*Micropterus salmoides*
Mandarin fish/Chinese perch	*Siniperca chuatsi*
Mozambique tilapia	*Oreochromis mossambicus*
Mud crab	*Scylla serrata*
Nile tilapia	*Oreochromis niloticus*
North African catfish	*Clarias gariepinus*
Olive flounder	*Paralichthys oliuaceus*
Oriental river prawn	*Macrobrachium nipponense*
Pacific white shrimp/white-leg shrimp	*Litopenaeus vannamei*
Polack/pollack bone frame	*Pollachius pollachius*
Puffer fish	*Fugu spp*
Red drum	*Sciaenops ocellatus*
Red sea bream/sea bream	*Pagrus major*
Seabass/Japanese seaperch/perch	*Lateolabrax japonicus*
Silver carp	*Hypophthalmichthys molitrix*
Snakehead	*Ophicephalus argus, Channa spp.*
Soft-shell turtle	*Trionyx sinensis*
Swamp eel/mud eel	*Monopterus albus*
Swimming crab/gazami crab	*Portunus trituberculatus*
Turbot	*Psetta maxima*
Walking catfish	*Clarias batrachus*
Wuchang bream/white amur bream/bluntnose black bream	*Megalobrama amblycephala*

Appendix B. Nutrient requirements of selcted aquaculture species

B.1. Dietary essential amino acid requirements of fleshy prawn and red sea bream (g/kg diet)

EAA	Fleshy prawn	Red sea bream
Methionine	12.4	5.3
Threonine	17.8	4.1
Valine	21.4	8.0
Isoleucine	17.6	2.0
Leucine	29.3	10.5
Phenylalanine	14.7	33.7
Lysine	31.0	23.9
Tryptophan	3.2	-
Histidine	8.6	4.0
Arginine	40.0	4.7

Source: Wang and Wang (2001) for fleshy prawn and Lei (2005) for red sea bream

B.2. Dietary vitamin and trace mineral requirement for fleshy prawn *P. chinensis* (mg/kg of diet, unless otherwise specified)

Vitamin	Requirement
A	12 000-18 000 IU
D	6000 IU
E	36–44
K	3.2–3.6
B_1 (Thiamine)	6
B_2 (Riboflavin)	10-20
B_3 (Nicotinic acid)	40
B_5 (Calcium pantothenate)	10
B_6 (Pyridoxine)	14
B_7 (Biotin)	0.08
B_9 (Folic acid/pteroylglutamic acid)	0.5
B_{12} (Cyanocobalamin)	0.001–0.002
C (LAPP 15%)	400
Inositol	400
Choline chloride	400
Trace mineral	
Selenium	20
Copper	30
Cobalt	30
Zinc	100–200
Iodine	30
Manganese	60–80

Source: Wang and Wang (2001)

B.3. Dietary vitamin and mineral requirements of Nile tilapia (mg per kg diet unless otherwise specified)

Vitamin	Amount
B_2 (Riboflavin)	5–6
B_3 (Niacin)	6–10
B_{12} (Cyanocobalamin)	NR
C	40–125
D	375 IU
E	25–100
Choline	NR
Mineral	
Calcium	0.7%
Manganese	2.5
Phosphorus	0.45–0.9%
Zinc	20–30

NR = no requirement established.

Source: Fred (2001)

Analysis of feeds and fertilizers for sustainable aquaculture development in India

S. Ayyappan
Indian Council of Agricultural Research
Krishi Anusndhan Bhavan, Pusa, New Delhi 110 012
India
S. Ahamad Ali
Central Institute of Brackishwater Aquaculture
75, Santhome High Road, RA Puarm, Chennai 600 028
India

Ayyappan, S. and Ahmad Ali, S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in India. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 191–219.

SUMMARY

Fisheries and aquaculture contribute significantly towards the Indian agricultural economy. Total fisheries production during 2003–04 was 6.4 million to which aquaculture contributed about 2.37 million tonnes. The share of fisheries in the national GDP is 1.4 percent and in the agricultural GDP its share is 4.5 percent. Aquaculture has been growing rapidly over the last two decades, contributing 37–38 percent of total fish production. India has substantial aquatic resources to diversify and expand its aquaculture sector. The major species groups that are farmed in India are fresh water fishes, freshwater prawns, penaeid shrimps, mud crabs and brackish-water fishes. Aquaculture is practised in a variety of agro-climatic zones ranging from tropical to temperate areas. Freshwater aquaculture is the largest contributor to aquaculture production and has grown at an average rate of 6.6 percent per annum. The most important species are the Indian major carps (*Catla catla, Labeo rohita, Cirrhinus cirrhosus)*, common carp (*Cyprinus carpio)*, grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), and giant freshwater prawn (*Macrobrachium rosenbergii)*. Fish species such as snake heads (e.g. snakehead murrel *Channa striata*) and catfishes (e.g. walking catfish *Clarias batrachus,* North African catfish *C. gariepinus,* stinging catfish *Heteropneustes fossilis,* sutchi catfish *Pangasius hypophthalmus*) are farmed, but to a lesser extent. Cold-water fish such as trout (rainbow trout *Oncorhynchus mykiss,* brown trout *Salmo trutta fario*, snow trout *Schizothorax richardsonii)* and golden mahseer (*Tor putitora)* are cultured in the uplands of northern India, mainly for sport fisheries. Freshwater fishes are cultured and produced in diverse farming systems (extensive to intensive) and farming practices are tailored to match the availability of inputs and the investment capabilities of the farmers.

Brackish-water aquaculture in India is synonymous with penaeid shrimp aquaculture. Because of its rapid growth rate and better market price, black tiger shrimp (*Penaeus monodon*) is the most important penaeid aquaculture species. Indian white shrimp (*Fenneropenaeus indicus*) is another important species and farmers have begun to show interest in Pacific white shrimp (*Litopenaeus vannamei*), though the culture of this species is currently not permitted. Species like *P. semisulcatus, Marsupenaeus japonicus* and *P. merguiensis* are available as alternatives, but have not become very popular. Extensive shrimp culture has been practised in India for over 100 years. Traditional shrimp aquaculture is based on wild juveniles that are trapped in ponds. Because of the demand for shrimp, farmers have changed their farming approach. Small and marginal farmers use improved extensive and semi-intensive systems, while large farmers and corporate companies practise semi-intensive and intensive shrimp culture. The total area under shrimp culture is around 150 000 ha and shrimp production has grown at an average of seven percent per annum during the last 15 years. Except for traditional farming systems, shrimp farming is not permitted within the Coastal Regulation Zone. Shrimp farming in India is a regulated activity under the auspices of the Aquaculture Authority of India, which ensures that the development of the industry progresses in an environmentally sustainable manner. Low-density shrimp culture with a stocking density of 6 PL/m^2 and production targets of 1 000–1 500 kg/ha/crop is advocated to achieve the goals of sustainable shrimp culture. The mud crabs *Scylla tranquebarica* and *S. serrata* are the most popular brackish-water crab species cultured in India.

Asian seabass/barramundi (*Lates calcarifer*), grey mullets (*Mugil* spp.), milkfish (*Chanos chanos*) and pearlspot (*Etroplus suratensis*) are the important brackish-water finfish species farmed in India. Seed of all species is collected from the wild and this limits the growth of brackish-water fish farming. Recent advances in seabass propagation are likely to stimulate the growth of this sub-sector.

Nutrients from fertilizers (organic and inorganic) and feeds are used in Indian aquaculture. While fertilizers are used mainly for initiating and maintaining natural productivity, feeds are used only under semi- and intensive culture conditions. Poultry

manure is rapidly becoming the fertilizer of choice. Of the total N and P fertilizers produced in the country, aquaculture uses only about 0.53 and 4.27 percent of nitrogen and phosphorus fertilizers, respectively.

Fishmeal production in India is split into the production of sterile fishmeal (crude protein 55–60 percent) and a lower quality fishmeal, which is made from sun dried trash fish. The quantity of sterile fishmeal produced in the country is only about 5 000–6 000 tonnes while 176 400 tonnes of dried trash fish is available for the production of lower grade fishmeal. Besides this, mantis shrimp (57 940 tonnes), shrimp head (31 235 tonnes) and sergisted shrimp (48 000 tonnes) are available for inclusion into aquafeeds. Among the plant protein resources, approximately 5.0–5.5 million tonnes of soybean meal is available per annum. Groundnut cake is generally accessible and readily available. Other important plant ingredients that are available for aquafeeds are cottonseed meal, coconut cake, sesame cake, mustard cake, rape seed cake and sunflower cake meal. Cereals such as wheat, rice, maize, sorghum and other millets are cultivated in the country. Cassava is also cultivated in some parts of the country. Rice bran and wheat bran are conventionally used in aquafeeds. Non-conventional aquafeed ingredients such as blood meal, meat meal, bone meal and poultry feather meal and silkworm pupae are also available. Vegetable oils such as groundnut oil, coconut oil, sunflower oil, sesame oil, mustard oil, soybean oil, soy lecithin, palm oil and, of late, rice bran oil are produced in the country. Fish oil is also produced, but on a very limited scale.

The farm-gate price of fish determines the choice of culture system, feeds and feed management practices. For carps, farmers use the mixture of rice bran and/or wheat bran and oilseed cake feed along with natural plankton production through periodic organic and inorganic fertilization. Shrimp farmers use a variety of feeds and feeding practices, ranging from single item feeds to farm-made feeds, using three to four ingredients, to "made to order feeds" and industrially manufactured extruded shrimp feeds. The "made to order" feeds are manufactured by small-scale manufacturers who make the feeds according to the customers' requirements and choice of the ingredient. Shrimp feed production in the country has increased from 30 000 tonnes in 1990 to 193 500 tonnes in 2004.

Aquaculture production is expected to reach 6.282 million tonnes by 2020. It has been calculated that the estimated fertilizer demand for aquaculture can be met comfortably. The requirement for nitrogen and phosphorus fertilizers will be about 1.0 and 8.2 percent, respectively of their total production. The position with regard to the availability of rice bran, wheat bran and oil cakes is also more than adequate for the future expansion of aquaculture.

Shrimp production is projected to reach 236 000 tonnes by 2020. It has been shown that the industrial and small-scale feedmills will be able to supply the future feed demands, although fish oil may be in short supply. There is a need to explore the replacement of fish oil with vegetable oils.

Several priority issues have been identified that may require attention for aquaculture to develop on a sustainable basis. These include improved feed formulation, the production of high quality, water stable feeds and improved methods of feed management. Such advances will ensure a reduced environmental impact of aquaculture and will contribute greatly towards satisfying consumer demands. Moreover, the promulgation of the Coastal Aquaculture Bill (2005) empowers government agencies to regulate and monitor for the sustainable development of the sector.

1. GENERAL OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

India's total fish production in 2004 amounted to 6.4 million tonnes, to which aquaculture contributed 2.37 million tonnes (37.0 percent). The fisheries sector (capture fisheries and aquaculture) contributes significantly to the Indian agricultural economy (Table 1). More than seven million fishers and fish farmers depend on fisheries and aquaculture for their livelihood. It is estimated that a further six million people are engaged directly and indirectly in related industrial activities.

Aquaculture has shown significant growth in the last two decades and has transformed itself into an industry contributing substantially to food production, both in terms of quantity and value. Capture fisheries are stagnating. Fortunately aquaculture has been making increasing and significant contributions to the national fish supply. The country is endowed with substantial aquatic resources (Table 2) and a diverse fish fauna. Both freshwater as well as brackish-water aquaculture are practised in the country.

TABLE 1
Facts and figures about fisheries and aquaculture in India. Information refers to the period of 2003–04 except where otherwise indicated

Parameter	Value
Total fish production (million tonnes)	6.40
Inland fish production (million tonnes)	3.46
Marine fish production (million tonnes)	2.94
Area under freshwater aquaculture (thousand ha)	600.00
Area under freshwater prawn culture (thousand ha)	41.87
Area under shrimp culture (thousand ha)	151.00
Annual growth (%) rate of inland fisheries (1991–2000)	6.60
Annual growth (%) rate of marine fisheries (1991–2000)	2.20
Share of aquaculture (%) in total fish production	37.00
Share of fisheries in gross domestic product (GDP) (%)	1.40
Share of fisheries in agriculture GDP (%)	4.50
Total quantity of fish export (thousand tonnes)	461.33
Export earnings of fisheries products (US$ billion)[1]	1.48
Share (%) of shrimp of total fisheries export	63.50
Share (%) of fish of total fisheries export	34.62

Source: Ayyappan and Biradar (2004); Agricultural Research Data Book (2004); MPEDA[2] (2004)

TABLE 2
The available aquatic resources for fresh and brackish-water aquaculture in India, 2003

Name of water resource	Area available (million hectares)	Area utilized for aquaculture (%)
Freshwater resources		
Ponds	2.25	11.0
Natural depressions	1.30	10.0
Reservoirs	3.00	9.0
Brackish-water resources	1.24	12.0

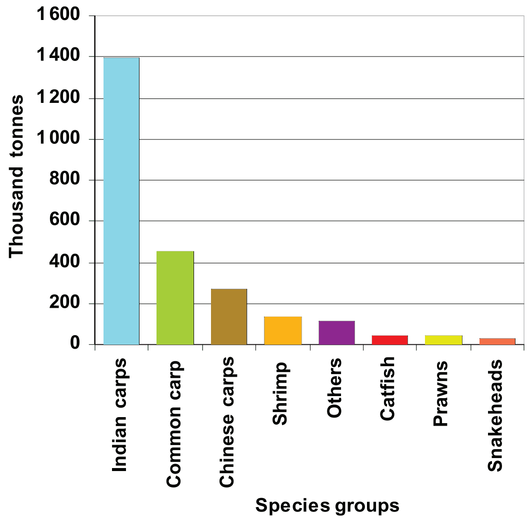
A wide range of freshwater, brackish-water and marine aquatic organisms are cultured in India (Table 3). The major groups are freshwater fish and prawns, penaeid shrimps, crabs and brackish-water fishes (Figure 1).

1 US$1.00 = Rs 43.00 (Indian Rupee, INR) (May 2005)
2 Marine Products Export Development Authority

1.1 Freshwater Aquaculture

Freshwater aquaculture is the largest contributor to aquaculture production in the country. During the 1990s this sector grew at a rate of 6.6 percent per annum. The establishment of the Freshwater Fisheries Development Agency (FFDA), which operates at the state level, has helped to increase the total production as well as yield from 600 kg/ha/year in 1975 to 2 200 kg/ha/year in 2000 (Ayyappan and Biradar, 2004). The most important species cultured are the Indian major carps, common carp, grass carp, silver carp and giant freshwater prawn. Air breathing fish such as clariid catfish are cultured to a lesser extent. Cold-water fish such as rainbow trout, snow trout and mahseer are cultured in the uplands of northern India. The latter however is a small-scale activity that caters mainly for the needs of sport fishing.

FIGURE 1
Production of major species groups in India in 2004



Source: FAO (2006)

Freshwater fishes are produced in a variety of systems, each of which has developed in relation to the availability of inputs in the region and the investment capabilities of the farmers (Ayyappan, 1997). Culture systems mainly consist of polyculture of Indian major carps (mixed farming) and the culture of exotic carps along with Indian major carps (composite fish culture). These combinations are practised under various conditions, including fertilizer and feed based systems, waste water based systems, biogas slurry systems, aquatic weed systems, agriculture/horticulture based systems and live-stock based systems, also known as integrated fish farming. Air breathing fishes are cultured either in mono or polyculture systems. Based on the criteria above,

TABLE 3
Major groups of fish and shellfish cultured in India during 2003

Group/sector	Species	Annual production (million tonnes)	Domestic market value (million US$)
Freshwater finfish			
Indian major carps	*Catla catla, Labeo rohita* and *Cirrhinus cirrhosus*	2.61	3 035
Common carp	*Cyprinus carpio*		
Grass carp	*Ctenopharyngodon idella*		
Silver carp	*Hypophthalmichthys molitrix*		
*Others**			
Brackish-water finfish			
Milkfish, mullets, Asian seabass, pearlspot		0.01	0.02
Freshwater crustaceans			
Giant freshwater prawn	*Macrobrachium rosenbergii*	0.036	356
Monsoon river prawn	*Macrobrachium malcolmsonii*		
Brackish-water Crustaceans**			
Penaeid shrimp	*Penaeus monodon* and	0.10	1 480
	Fenneropenaeus indicus		
Mud crabs	*Scylla tranquebarica* and *Scylla serrata*	0.05	6.4

*Others primarily include snakeheads, cat fishes, coldwater fish and mahseer; **Estimated market value of brackish-water crustaceans are based on export earnings;
Source: Ayyappan and Biradar (2004); Agricultural Research Data Book (2004); MPEDA (2004); Kathirvel, Pandian and Balasubramanian (2004)

TABLE 4
Culture systems and production levels of freshwater carps, 2004

Culture System	Yield (tonnes/ha/year)
Composite fish culture	4 – 6
Sewerage based fish culture	3 – 5
Weed based polyculture	3 – 5
Biogas slurry fish culture	3 – 5
Integrated fish farming	3 – 5
Intensive culture (with feed and aeration)	10 – 15

TABLE 5
Area under freshwater prawn culture and production in different states, 2004

State	Area developed (ha)*	Area under culture (ha)**	Total production (tonnes)	Yield (tonnes/ha/year)
West Bengal	4 532	4 450	2 435	0.55
Orissa	3 000	470	450	0.96
Andhra Pradesh	32 290	27 286	32 085	1.18
Tamil Nadu	380	159	133	0.84
Kerala	886	886	238	0.27
Karnataka	256	206	113	0.55
Maharashtra	7 139	6 981	306	0.04
Gujarat	1 440	1 430	106	0.07
Total	49 920	41 870	35 870	**0.86**

*Area developed and ready for prawn culture; **area presently used for prawn culture

Source: MPEDA (2004)

aquaculture is practised at three levels of intensity. Large waterbodies of 20–25 ha are used for extensive aquaculture. In these systems the fish are produced on natural food production without the application of external inputs. Semi-intensive fish production systems are those in which supplementary feeding is provided in addition to the application of fertilizers to improve natural productivity. Intensive fish production systems are those in which the fish are fed balanced feeds, while pond water is aerated and exchanged at predetermined intervals. The various culture systems adopted for Indian carp culture have been well standardized and the production levels achieved in these systems are summarized in Table 4.

In recent years, giant freshwater prawn (*Macrobrachium rosenbergii)* culture has become an important aquaculture activity in many states of India and particularly in Andhra Pradesh. This was mainly driven by the closing of the culture cycle and the commercial scale production of prawn seed. It is estimated that 41 870 ha are currently used for prawn culture (Table 5) and approximately 35 870 tonnes were produced in 2003/04. Prawns are produced in extensive, mixed and semi-intensive culture systems. Organic manures and fertilizers are applied in ponds and the prawns are fed with formulated pellet feeds. In extensive culture systems ponds are stocked with nursery reared juveniles (3–5 g) at 8 000 to 15 000/ha. In mixed culture systems prawns are reared together with Indian major carps (catla and rohu). Under semi-intensive, monoculture conditions ponds are stocked at 50 000/ha and production levels are in the range of 350 to 2 000 kg/ha/crop. Production levels of prawn under mixed culture conditions are highly variable depending upon the stocking density used and the fish production ranged from 150 to 2 500 kg/ha/year (Rao, Anandakumar and Sinha,1999).

1.2 Brackish-water Aquaculture

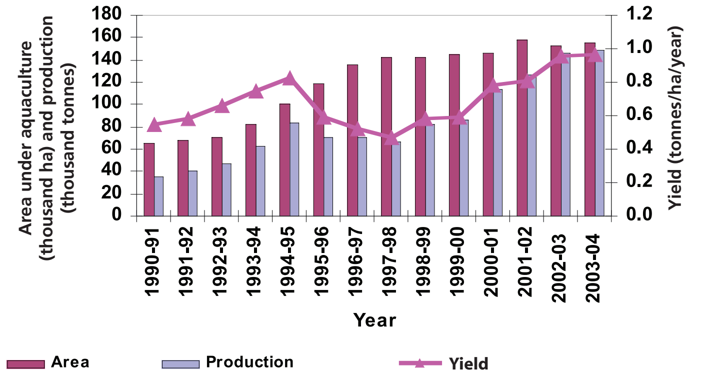
Brackish-water aquaculture in India is synonymous with penaeid shrimp aquaculture. Black tiger shrimp (*Penaeus monodon*) is the most popular species for aquaculture, while Indian white shrimp (*Fenneropenaeus indicus*) is also cultured. Recently there has been interest in the farming of Pacific white shrimp (*Litopenaeus vannamei*), though the culture of this shrimp is not officially endorsed.

TABLE 6
Area under shrimp farming in different states and shrimp production, 2004

State	Potential area available (ha)	Area developed (ha)*	Area under aquaculture (ha)**	Total production (tonnes)	Yield (tonnes/ha/year)
West Bengal	40 500	50 405	49 925	29 714	0.60
Orissa	31 600	12 880	12 116	12 390	1.02
Andhra Pradesh	150 000	79 270	69 638	53 124	0.76
Tamil Nadu	56 800	5 416	3 214	6 070	1.89
Kerala	65 000	16 323	14 029	6 461	0.46
Karnataka	8 000	3 435	3 085	1 830	0.59
Goa	18 500	1 001	963	700	0.73
Maharashtra	80 000	1 056	615	981	1.60
Gujarat	376 000	1 537	1 013	1 510	1.49
Total	1 190 900	171 320	154 600	112 780	0.73

*Area developed and readily available for shrimp culture; **area presently used for shrimp culture.
Source: MPEDA (2004)

FIGURE 2
Expansion of area under shrimp culture and shrimp production in India



Source: MPEDA (2004)

Shrimp aquaculture in India has been practised for more than 100 years, in the 'pokkali[3]' fields of Kerala state and under 'trap culture' conditions in 'Bheries[4]' in West Bengal, Karnataka and Goa. These traditional culture systems are shallow ponds used for paddy cum shrimp/fish culture, where tidal inflow provides the seed stock. Because of declining shrimp stocks farmers are supplementing the wild shrimp seed with hatchery reared PLs. Since there is no selective stocking of the ponds with a particular species, the systems are best described as multi-species polyculture of shrimp and finfish. Harvesting occurs during the spring tides by fixing a bag net in the sluice gate during the outgoing tide. The shrimp species harvested from these systems are predominantly *Fenneropenaeus indicus*, *Penaeus merguinensis*, *Metapenaeus dobsoni* and *M. monoceros*. Miscellaneous fish species such as mullet (*Mugil* spp.), milkfish (*Chanos chanos*), and pearlspot (*Etroplus suratensis*) are harvested along with shrimp. It is estimated that some 50 000 ha are used for traditional shrimp farming. Economically shrimp are the most important species in these systems and production ranges from 200–500 kg/ha/cycle.

The advent of hatchery production of shrimp seed and the subsequent adoption of shrimp monoculture systems in the 1980s transformed shrimp farming into a billion dollar industry in India. Small and marginal farmers mainly practise improved extensive and semi-intensive farming at stocking densities of 3–5/m^2 and 10–20/m^2, respectively, while larger farmers and corporate farms use semi-intensive and intensive technologies at stocking densities of 20–100 PL/m^2. The principal culture species are *P. monodon* and *F. indicus.* Production levels in the various systems ranges form 500 kg/ha/crop in extensive systems, 2 000–4 000 kg/ha/crop in semi-intensive systems

[3] Tall growing variety of paddy commonly cultivated in the state of Kerala
[4] Traditional farming system of shrimp with a large water spread area

and 5 000–16 000 kg/ha/crop in intensive culture systems. The total area under shrimp culture systems has expanded rapidly in different states (Table 6) and production has shown rapid growth (Figure 2).

Shrimp farming in India took a negative turn in 1995 with the occurrence of WSSV (white spot syndrome virus) disease outbreak. Simultaneously environmental and legal issues also surfaced. The Supreme Court of India in its judgement in 1996 directed that construction of shrimp culture ponds and shrimp culture activity should not be permitted within the Coastal Regulation Zone, except for traditional and improved traditional types of culture practised in low lying coastal areas. In pursuance of the directive of the Supreme Court, the Govt. of India set up a statutory body 'The Aquaculture Authority of India' under the Environmental Protection Act (1986). The main functions of the Aquaculture Authority are to regulate shrimp culture in the coastal areas and to promote sustainable and environmental friendly shrimp farming in the country. Since then, low-density shrimp culture with a stocking density of 6 PLs/m^2 and production targets of 1 000–1 500 kg/ha/crop is advocated. However, a large number of farmers are still using stocking densities of 20/m^2 and above. Recently parliament has passed the Coastal Aquaculture Bill (2005), which empowers the government to regulate and monitor the sector's sustainable development.

Parallel to these transformations in the industry there has been a search for alternative shrimp species. This is mainly because the entire shrimp farming industry is largely dependent on tiger shrimp. However, due to the superior growth and value of the tiger shrimp this is proving to be difficult.

1.2.1 Finfish aquaculture

Asian seabass (*Lates calcarifer*), grey mullets (*Mugil* sp.), milkfish (*Chanos chanos*) and pearlspot (*Etroplus suratensis*) are the most important species. The non-availability of seed on a commercial scale is the most limiting factor for finfish aquaculture. Breeding and larval rearing technologies have recently been developed for Asian seabass (Arasu, Abraham and Kailasam, 2004) and this is expected to stimulate the sector.

1.2.2 Mudcrab aquaculture

The mud crab species, *Scylla serrata* and *S. tranquebarica* are the most popular brackish-water crab species cultured in India. Mud crabs are cultured in traditional shrimp culture fields in the states of West Bengal, Kerala, Karnataka and Tamil Nadu. Production is reported to be within the range of 10–35 kg/ha/year (Kathirvel, Pandian and Balasubramanian, 2004). Juvenile mud crabs are also collected from the wild and cultured on a small scale in fenced earthen ponds and in cages. They are stocked at 1–2 juveniles/m^2 and fed fresh trash fish, clam meat and slaughterhouse waste at 5–10 percent of biomass. Crabs are cultured for 7–10 months and harvested at 500–600 g weight and production in these systems range from 500–1 000 kg/ha/crop. Mud crabs are also farmed in polyculture with milkfish and grey mullets in some areas (Kathirvel, Pandian and Balasubramanian, 2004). Fattening of soft, post-moulted mud crabs is also practised in earthen ponds and cages. Fattening and hardening is normally undertaken for a period of 25–30 days, during which they are fed with feeds, as previously mentioned, and then exported. Crab fattening is very profitable and is becoming increasingly popular. Exported figures for crabmeat and live crabs in 2004 were 141 tonnes (US$1.0 million) and 1 896 tonnes (US$5.36 million), respectively. Large scale hatchery propagation still needs to be perfected.

2. REVIEW AND ANALYSIS OF AQUACULTURE FEEDS AND FEED INGREDIENTS

Nutrients from both fertilizers and feeds are used in Indian aquaculture. Fertilizers are used primarily for initiating and maintaining natural productivity and feeds are used in semi-intensive and intensive culture practices.

TABLE 7

Manures and fertilizers used in freshwater fish aquaculture

Manure/fertilizer	Application rate (tonnes/ha/year)	Remarks
Lime	0.10–1.25	Applied prior to fertilization
Cow dung	20.0–25.0	50% of total amount is used as an initial dose, mixed with 10–25 kg of single super phosphate and the remaining amount in monthly intervals
Poultry manure	8.0–10.0	As above
Urea or di-ammonium phosphate, Single superphosphate	0.2–0.5	Applied in monthly/fortnightly intervals

2.1 Use of fertilizers and manure in aquaculture

The major aquaculture activity in India is the culture of freshwater fish, which is principally based on natural food production through the use of fertilizers and manures. The culture technology of Indian major carps and other carps in different types of culture systems (Veerina *et al*., 1993), involves the periodical application of fertilizers and manures in ponds. Prior to the application of fertilizers some farmers apply agricultural lime and dolomite at 100 kg/ha. After two to three days of liming, fertilizers are applied. Both organic manure (including cow dung slurry from bio-gas plants) and chemical fertilizers are used. The present trend is that more farmers are using poultry manure. In recent years, farmers have also started using bio-fertilizers at 1–2 tonnes/ha. The type of commonly used fertilizers and application rates are presented in Table 7.

Freshwater prawn ponds are fertilized with manures and inorganic fertilizers. Ponds are dried for 4–8 weeks after harvest and then ploughed using tractors. Once every two years the surface soil is removed and used for agricultural purposes. Lime is applied at variable application rates (100–1 200 kg/ha), depending on soil pH. Some farmers also apply dolomite at 100 kg/ha. Cattle manure is applied at 0.5–5.0 tonnes/ha and poultry manure at 2.0 tonnes/ha. Inorganic fertilizer application rates are urea 5–50 kg/ha, single superphosphate 6–85 kg/ha and ammonium phosphate 8–125 kg/ha (Rao, Anandakumar and Sinha, 1999).

In shrimp aquaculture, manure and fertilizer are also used during pond preparation. The primary function of fertilization in semi-intensive and intensive shrimp ponds is to develop green water (phytoplankton) before stocking and to maintain the same throughout the culture period. Based on the nutrient availability in the soil, the recommended application rates are: nitrogenous fertilizer (urea or ammonium phosphate) 15–20 kg/ha/year, phosphate fertilizer (super phosphate) 10 kg/ha/year, organic manure (cattle dung or poultry manure) 1 000–1 500 kg/ha/year. No fertilizers are, however, used in traditional shrimp culture systems.

2.2 Availability of fertilizers

Agriculture being the mainstay of the Indian economy, fertilizers and manures are produced on a large scale (Table 8). A total of 19.42 million tonnes of nitrogenous fertilizers and 2.41 million tonnes of phosphate fertilizers were produced in 2002/03. In addition, approximately 615.6 million tonnes of cattle manure and 14.9 million tonnes of poultry manure are available annually. Approximately 16.2 percent of cattle manure is used in aquaculture. Bio-fertilizers are also produced and used in agriculture. Aquaculture uses about 0.53 percent of the nitrogen fertilizer and 4.27 percent of the annual phosphorus fertilizer production.

2.3 Feed ingredients and feeds used in aquaculture

Conventional feed ingredients such as rice bran, wheat bran and groundnut cake are extensively used for feeding carps in freshwater aquaculture. Dried trash fish powder,

TABLE 8
Estimated availability of fertilizers and manures in India (2002/03) and their use in aquaculture

Fertilizer/manure	Nutrient (%)	Quantity available (million tonnes)	Estimated use in aquaculture (million tonnes)
Ammonium sulphate	Nitrogen 20.6	0.54	
Ammonium chloride	Nitrogen 25.0	0.08	
Calcium ammonium nitrate	Nitrogen 25.0	0.17	
Urea	Nitrogen 46.0	18.62	
Total nitrogenous fertilizers		**19.42**	**0.103**
Single super phosphate	Phosphorus (P_2O_5) 16.0	2.41	
Total phosphate fertilizers		**2.41**	**0.103**
Cattle manure		615.6	100.2
Poultry manure		14.9	
Total organic manure		**630.5**	**150.3**

Source: Agricultural Research Data Book (2004)

silkworm pupae and defatted oilseed cakes and meals (soybean, mustard, sesame and cotton seed) are occasionally used. Non-conventional feed ingredients (alternative ingredients other than usually used) from animal by-products such as meat meal, meat and bone meal, blood meal and *Azolla* (Mohanty and Das, 1995), are seldom used due to the uncertainty of supply. Trash fish, poultry offal and other animal by-products are used for carnivorous fish culture. Both conventional and non-conventional feed ingredients are used in formulating feeds for shrimp and giant freshwater prawn (Alagarswami and Ahamad Ali, 2000; Dani, 2000; Pandian, 2000; Paul Raj, 2000). Feed ingredients of marine origin such as fishmeal and fish oil are extensively used in shrimp and prawn feed formulations. Shrimp meal, squid products and mantis shrimp meal are also in great demand.

2.4 Availability of feeds and ingredients

2.4.1 Ingredients of marine and animal origin

The demand for feed ingredients of marine animal origin by the shrimp feed industry is increasing rapidly. Other animal by-products such as meat and bone meal and blood meal are also available, but their use by industrial feed manufacturers is minimal due to limited availability. Table 9 provides estimates of the availability of feed ingredient of marine origin (Table 9).

Approximately 5 000–6 000 tonnes of high quality fishmeal (crude protein (CP) 55–60 percent) is produced annually. In addition, about 176 400 tonnes of low value, sun dried trash fish is available annually. This is known as feed-grade dry fish, which is pulverized and sold as fishmeal. Besides this, mantis shrimp (57 940 tonnes), shrimp head (31 235 tonnes) and sergisted shrimp (48 000 tonnes) are available. It is expected that at least 40 percent of these ingredients are used by the aquafeed industry and the rest are used by the poultry and other livestock feed industries. Of the estimated 176 400 tonnes of low value sun dried trash fish, an estimated 100 000 to 130 000 tonnes is powdered as dry fishmeal (with CP <50 percent and 16–20 percent total ash) (Ahamad Ali *et al*., 1995; Alagarswami and Ahamad Ali, 2000; Pandian, 2000; Paul Raj, 2000). The mixed dry fish consists mainly of juvenile carangids, sciaenids, silver bellies, anchovies, sardines, mackerel and lizardfish. The pulverized fishmeal is used mainly for producing supplementary feeds for shrimp and prawns by small-scale, local feed mills. The increasing demand for marine fish for human consumption has put pressure on the supply of "trash" fish, the availability of which is rapidly declining. The poultry feed industry is the biggest competitor for fishmeal. However, decreasing inclusion rates of fish products in poultry feeds has increased the availability of fishmeal for aquaculture. Mantis shrimp (*Oratosquilla* sp) has emerged as a potential marine protein source (CP 45 percent dry weight) for aquafeeds (Ahamad Ali, 1982; 1992; Ahamad

TABLE 9

Estimated availability and cost of marine and other animal protein resources in India

Ingredient	Crude protein content (%)	Quantity available (thousand tonnes)	Cost (US$/kg)
Marine ingredients – indigenous			
Fishmeal (sterile CP 60%)	55.0–60.0	5–6	0.82
Dry fish (feed grade) or pulverized fishmeal	45.0–55.0	177	0.58
Mantis shrimp (*Squilla* sp.)	42.0–45.0	58	0.23
Sergisted shrimp (*Acetes*)	55.0–60.0	48	0.69
Shrimp head waste	32.0–38.0	31	0.19
Cuttlefish	40.0–45.0	4	1.16
Squid	55.0–68.0	7	1.16
Clam meat	40.0–48.0	4	1.16
Mussel meat	50.0–55.0	1	1.16
Small crabs	38.0–42.0	6	0.16
Marine ingredients – imported			
Fishmeal (CP >60%)	60.0–70.0	20–25	1.05–0.94
Fish soluble	55.0–60.0	3–5	1.63
Squid meal	60.0–65.0	5	1.60
Squid liver meal	45.0–55.0	3–5	1.16

Source: Ahamad Ali *et al*. (1995); Dani (2000); Pandian (2000); Paul Raj (2000); Agricultural Research Data Book (2004)

Ali and Mohamed, 1982) and is now increasingly being used in feeds for shrimp and prawns. The chitin manufacturing industry and the poultry feed industry are the major competitors for this raw material, though the supply is adequate for aquaculture.

Squid, shrimp and mollusc meal (clam and mussel) are primarily used as feed attractants and for growth promoters for shrimp besides being good protein sources. These ingredients are largely not accessible and not available because the resources are small and the product is in great demand for human consumption and for export. Hence these products are imported by the aquafeed industry. Squid and cuttlefish processing waste products are valuable ingredients for shrimp feeds (Ahamad Ali, 1998), though supply is limited.

2.4.2 Ingredients of plant origin

Plant ingredients constitute the largest nutrient resources for aquafeeds. Their use as protein, lipid and energy (carbohydrate) sources in feed formulations are shown in Table 10.

Protein sources

Soybean meal is the most important of the plant protein sources. Soybean cultivation is on the increase in the country and hence the outlook for the availability of soybean meal for aquafeeds is positive. Soybean meal contains several anti-nutritional factors (Table 11), though these can be destroyed by heat treatment. Corn (maize) gluten, a by-product of the corn starch manufacturing industry, is another promising plant protein source. It has a 45–50 percent crude protein content but is deficient in some amino acids, especially arginine and lysine. However, it can be used along with other protein sources in aquafeeds. Preliminary studies have shown that corn gluten can partially replace (10–15 percent) fishmeal in Indian white shrimp feed (Ahamad Ali, Syama Dayal and Ambasankar, 2004). Corn gluten has also been evaluated in the diets of Indian carps (Kaur, 2002).

Groundnut oilseed cake is sought after by both the terrestrial animal and the aquafeed industries. Groundnut cake is extensively used in cattle, poultry, fish and shrimp feeds and is readily available. Although its use in high quality shrimp feeds is limited, groundnut cake is utilized in considerable quantities in farm-made feeds and by small-scale feed producers.

Other important available plant protein sources are cottonseed meal, coconut oilseed cake, sesame cake, mustard cake, rape seed cake and sunflower oilseed cake meal. They are readily available to the aquafeed industry but their use in fish and shrimp feeds is limited due to various reasons. Their inclusion levels do not normally exceed 15 percent. With improved processing technology these resources could, in future, play a greater role in aquafeeds.

Energy sources

India produces a variety of cereals. The most of which prominent are wheat, rice, maize, sorghum and other millets. Tapioca tuber (cassava) is also cultivated in some parts of the country. All are excellent energy (carbohydrate) sources. Cereal grains are the primary staple foods in India and competition for their use is high. However, they are accessible and available for use in aquafeeds (Table 10). Wheat is most extensively used in shrimp feeds for its carbohydrate content as well as for its gluten content, which is a good binder, followed by rice and maize products. Sorghum, pearl millet and other coarse cereals such as ragi (milo) and finger millet are available, but not often used in aquafeed formulations.

The rice granaries of India produce large quantities of rice bran, most of which is used by the animal feed industry. Besides being a good source of energy, rice bran contains between 8–9 percent protein, lipids, B-group vitamins and cellulose. Rice bran is readily available for fish and prawn feeds.

Wheat bran is increasingly used in fish and prawn feeds, particularly in the northern states where wheat bran is more abundant compared to rice bran. Tapioca (cassava) is used in shrimp and fish feed formulations as a carbohydrate source and as a binder (Ahamad Ali, 1988).

TABLE 10

Estimated availability and cost of feed ingredients of plant origin for their potential use in aquafeeds in India

Ingredient	Annual availability (million tonnes)	Cost (US$/kg)	Potential use in aquafeeds (million tonnes)
Protein sources			
Soybean cake	5.0–5.5	0.30	0.0356
Groundnut cake	8.0–8.5	0.23	0.0202
Corn gluten	NA	0.25	NA
Cotton seed cake	0.75–0.80	0.18	0.0096
Sesame cake	0.45–0.50	0.23	0.0062
Sunflower cake	0.8–1.0	0.14	0.0034
Rape seed/mustard cake	5.0–5.8	0.19	0.0152
Linseed cake	0.1	NA	NA
Energy (carbohydrate) sources			
Coconut cake	0.14– 0.16	0.23	0.0019
Maize (2002–2003)	14.0–14.7	0.25	0.1476
Sorghum (2002–2003)	7.5–8.0	0.19	0.0102
Pearl millet (2002–2003)	11.0–11.8	0.2	0.0840
Other cereals (2002–2003)	31.8	0.19	0.3816
Wheat (2002–2003)	72.6	0.34	0.8713
Rice (2002–2003)	89.3	0.35	0.5817
Rice bran (including defatted bran 7%)	3.0–3.5	0.07–0.13	0.0242
Wheat bran	2.0–2.5	0.19	0.0186
Tapioca	5.6–6.0	0.14	0.0672

NA=No available data

Source: Ahamad Ali *et al.* (1998); Dani (2000); Pandian (2000); Paul Raj (2000); Agricultural Research Data Book (2004)

TABLE 11
Anti-nutritional factors in some plant ingredients

Ingredient	Potential anti-nutrient
Groundnut cake	Phytic acid & protease inhibitor
Soybean meal	Trypsin inhibitor
Mustard cake	Glucosinolates
Cotton seed cake	Gossypol & cyclopropionic acid
Sesame cake	Phytic acid & protease inhibitor
Rapeseed cake	Protease inhibitor and glucosinolates
Sunflower cake	Saponins & protease inhibitor
Lucaene leaf	Mimosin
Cassava leaf *(Manihot esculants*)	Hydrocyanic acid
Lupin seed cake	Saponins, alkaloid & protease inhibitor
Alfalfa meal (*Medicago* sp.)	Protease inhibitor, saponins, phytoestrgens

Source: Francis, Makkar and Becker (2001); Pandian (2000)

Lipid sources
India produces 4.87 million tonnes (2002–03) of edible oils (Table 12), such as groundnut, coconut, sunflower, sesame (gingili), mustard, soybean, soy lecithin, palm and to some extent rice bran oil. Fish and shark liver oil is also produced locally.

Because of its HUFA and PUFA composition, fish oil is the most sought after lipid source for aquafeed formulations (Hasan, 2001). The crude local fish oil is mainly used in the manufacture of farm-made feeds and by small-scale aquafeed producers. All major aquafeed companies import fish oil (approximately 5–6 thousand tonnes per annum). Plant oils, though available in the country, are not easily accessible by the aquafeed and animal feed industries because of the high demand for human consumption. Moreover, their fatty acid profiles do not adequately meet the essential fatty acid requirements of most of the cultured species. However, soybean oil and soy lecithin are used as sources of fat and phospholipids in shrimp feeds.

TABLE 12
Estimated availability of edible oils and fish oil in India

Type	Availability (thousand tonnes)	Cost (US$/kg)
Soybean oil	527	1.28
Groundnut oil	1 464	1.28
Sesame oil	227	1.86
Coconut oil	416	1.39
Sunflower oil	262	1.39
Safflower oil	0.45	1.86
Mustard oil/ rape seed oil	1 542	1.39
Cotton seed oil	358	1.28
Palm oil	NA	1.00
Soy lecithin	NA	0.93
Niger seed oil	0.27	1.63
Fish oil (indigenous)	5–6	1.39
Fish oil (imported)	5.0	2.34–3.48
Squid oil (imported)	3.0	3.5

Source: Agricultural Research Data Book (2004); Ahamad Ali *et al.* (1995)

2.4.3 Non-conventional feed ingredients
There are several non-conventional feed ingredients that are suitable and available for aquafeed formulations (Table 13). The usefulness of these ingredients has been tested for some fish species (Dhawan, Kaur and Virk., 2004). Some of these animal by-products are used for the feeding of carnivorous finfish and included, on a limited scale, in prawn and farm-made shrimp feeds. India also has a large sericulture industry and silkworm pupae are utilized for feeding fish, prawns and shrimps (Ahamad Ali, 1992).

TABLE 13
Estimated availability of non-conventional feed ingredients in India

Ingredient	Availability (tonnes)	Cost (US$/kg)
Animal products/by-products		
Meat and bone meal	55 200	0.14
Poultry offal	65 000	0.12
Feather meal	Available	NA
Slaughter house waste	Available	NA
Silkworm pupae	40 000	NA
Poultry hatchery waste	17 406	NA
Single cell proteins		
Spirulina	Available	14.0
Yeast	Available	2.8
Yeast extract (from brewery)	Available	1.16

NA= not available

Single cell proteins

Spirulina and single cell yeasts are used, to a limited extent, in shrimp larval feeds in India. *Spirulina* is rich in protein (60 percent) and contains pigments and antioxidants besides some unknown growth factors (Vaitheeswaran and Ahamad Ali, 1986). *Spirulina* has the potential to replace fishmeal to some extent, but the high nucleic acid content limits its use in aquafeeds. The large scale production of single cell proteins needs to be examined as protein sources for aquafeeds (Dani, 2000).

There are several other non-conventional feed ingredients (Dhawan, Kaur and Virk, 2004), that have been tested for some fish species (Table 14) with encouraging results. Press mud from the sugar cane industry was used to replace 25 percent of the rice bran in common carp feeds, without any adverse effects (Singh and Dhawan 1995; Singh, Dhawan and Saxsena, 1999). Molasses can be included at five percent in common carp diets (Singh and Dhawan, 1993). Poultry hatchery waste, silage from poultry offal meal, slaughter house waste and silk worm pupae have all been tested and found suitable for various fish species (Butt *et al*., 1988; Sehagal and Sharma, 1991; Swamy and Devaraj, 1995; Chakrabarti, 1996; Borthakur and Sharma, 1998; Singh, Kaur and and Dhawan, 2000).

TABLE 14
Experimental use of non-conventional feed ingredients for selected fish species

Feed/Ingredient	Species tested	Reference
Agro-industry products		
Sugar cane molasses	Common carp	Singh and Dhawan (1993)
Press mud	Common carp	Singh, Dhawan and Saxsena (1999); Singh and Dhawan (1995)
Animal by-products		
Poultry hatchery waste	Common carp	Singh, Kaur and and Dhawan (2000)
Poultry offal meal	Common carp	Chakrabarti (1996)
Slaughter house waste	Indian major carp, mrigal Common carp	Sehagal and Sharma (1991) Butt *et al.* (1988)
Silkworm pupae	Common carp Walking catfish (*Clarias batrachus*)	Swamy and Devaraj (1995); Borthakur and Sharma (1998)
Aquatic and terrestrial macrophytes		
Otellia	Indian major carps, catla and rohu	Patnaik *et al.* (1991)
Nymphoides	Indian major carps	Patnaik *et al.* (1991)
Pistia	Rohu	Ray and Das (1995)
Duck weed (*Lemna minor*)	Common carp	Devaraj, Krishna and Keshavappa (1981)
Azolla carolaniano *Azolla pinnata*	Catla, rohu and grass carp	Das, Sikdar and Chotterjee (1994); Mohanty and Das (1995)
Plant leaf & seed meals		
Lucerne (alfalfa) meal *Medicago sativa*	Common carp	Swamy and Devaraj (1995)
Acacia leaf meal (*Acacia auriculiformis*)	Rohu	Mondal and Ray (1996)
Sal seed (*Shorea robusta*)	Rohu	Mukhopadhyay and Ray (1997)

The proximate composition of some of the important feed ingredients is presented in Table 15.

TABLE 15
Typical proximate composition of selected feed ingredients

Ingredient	% dry matter basis						Information source
	Moisture	Crude protein	Crude lipid	Crude fibre	CHO	Ash	
Animal by-products							
Fishmeal (imported) Grade 1	8.1	70.5	8.5	0.1	Trace	12.8	2
Fishmeal (imported) Grade 2	9.1	69.2	6.5	0.1	0.8	14.3	2
Fishmeal (imported) Grade 3	5.0	66.6	9.5	0.2	0.2	18.5	2
Fishmeal (indigenous)	10.3	64.4	4.7	2.5	2.4	15.7	2
Fishmeal (indigenous)	10.8	55.0	5.4	1.7	3.3	23.8	2
Sergisted shrimp meal	9.8	60.2	6.8	4.4	3.6	15.2	2
Prawn head meal	9.9	39.8	9.6	16.4	4.1	20.2	2
Squid meal	8.4	66.5	4.4	3.9	5.9	10.9	2
Mantis shrimp (*Squilla*)	10.7	44.2	4.4	5.7	4.3	30.7	2
Clam meat meal	7.7	48.1	13.6	trace	23.0	7.6	2
Meat meal	8.0	50.0	4.4	6.8	25.8	5.0	2
Meat and bone meal	-	51.0	10.0	-	-	16.0	2
Blood meal	10.0	65.3	0.5	-	-	-	1
Silkworm pupae	9.8	62.2	7.6	1.3	1.9	17.2	2
Poultry feather meal	-	85.0	3.2	1.5	-	-	3
Poultry hatchery waste	-	40.0	-	-	15.2	18.0	3
Poultry offal	8.6	60.3	10.1	2.5	6.2	12.3	2
Plant and plant by-products							
Soybean meal	10.5	51.5	1.00	8.9	19.7	8.5	2
Corn (maize) gluten	6.8	48.2	2.4	4.8	34.0	3.8	2
Groundnut cake meal	7.7	48.4	7.6	2.1	28.2	6.0	2
Groundnut cake meal	13.1	46.9	5.0	8.9	18.0	8.1	2
Mustard cake	9.2	23.6	9.6	6.3	40.9	10.4	2
Sunflower cake meal	7.0	26.7	2.0	30.1	26.4	7.7	2
Sesame cake meal	4.9	34.0	10.8	13.0	24.8	12.5	2
Sesame cake meal	9.8	38.7	6.0	10.7	15.8	19.0	2
Rape seed cake meal	11.0	35.9	0.9	13.2	32.1	6.9	2
Sal seed cake meal	8.6	8.2	2.9	1.7	68.4	10.2	2
Cotton seed cake meal	7.0	37.0	6.7	13.0	35.3	1.0	2
Coconut cake meal	8.9	25.9	11.2	17.9	27.2	8.9	2
Coconut cake meal	8.4	20.3	11.4	16.2	37.5	6.2	2
Corn meal	10.4	9.5	4.0	3.8	68.7	1.7	1
Sorghum	10.0	9.0	2.8	3.0	75.1	0.1	1
Wheat flour	12.5	12.5	2.0	1.8	70.0	1.3	1
Rice flour	11.5	9.1	0.3	trace	78.6	0.5	1
Refined wheat flour	12.3	11.1	0.3	trace	75.2	1.2	1
Rice bran	8.7	9.0	4.5	13.2	40.8	23.8	1
Wheat bran	10.6	10.8	2.5	9.7	6.4	3.0	1
Tapioca flour	8.5	2.0	0.5	3.5	68.5	2.4	1
Pistia meal	4.9	19.5	1.3	11.7	37.0	25.6	1
Leucaena meal	11.8	33.1	4.7	9.0	34.2	7.2	1
Press mud from sugarcane industry	-	15.4	7.8	23.3	0.8	-	3
Molasses	-	3.2	-	-	60.8	5.0	3
Single cell protein							
Spirulina	7.8	60.9	9.0	7.5	1.8	13.0	1
Yeast (bakers)	1.4	56.1	2.1	0.3	30.2	9.9	1

CHO = digestible carbohydrate; blank indicates data is not available.

Source: 1) Nandeesha (1993); 2) Ahamad Ali, Gopal and Ramana (2000); 3) Dhawan, Kaur and Virk (2004)

3. ON-FARM FEED MANAGEMENT STRATEGIES

3.1 Freshwater fish

There are three recommended polyculture practices with standardized feeding regimens. These are:

- polyculture of catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus cirrhosus*) stocked at 4 000 to 5 000 fingerlings/ha at a species ratio of 2:3:2, respectively;
- polyculture of the three Indian major carps, plus silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) stocked at a ratio of 40 percent Indian carps (1:1:1 species ratio) and 60 percent other carps at a species ratio of 2:1:1 at a density of 10 000 fingerlings/ha; and
- polyculture of rohu and catla stocked at 10 000 fingerlings/ha at a ratio of 9:1 and or mixed with snakehead (*Chana striata*) at a ratio of (9:0.5:0.5).

For these combinations it is recommended that ponds are fertilized with organic and inorganic fertilizers and the fish are fed on a 1:1 mixed rice bran and groundnut oilseed feed at 2–3 percent of biomass per day. The average estimated production from these systems is about 10 tonnes/ha/year.

However, culture practices are modified to suit local demand, availability and cost of the required inputs and the farm-gate price of the fish. The average farm-gate value of Indian major carps is less than US$0.5/kg (Rs 25/kg). For example, in Andhra Pradesh farmers quickly modified the recommended culture combinations and soon developed unique fertilization, feeding and feed management practices. Ingredients are selected purely on the basis of availability and cost effectiveness. These adapted local technologies were largely responsible for the early success of fish farming in Andhra Pradesh, which subsequently stimulated fish culture throughout the country.

Fish farmers in Andhra Pradesh only use two species in their combination systems (viz. catla and rohu at a 20:80 ratio). The fish are stocked at 6–12 fry/m^2 in nursery ponds and reared to 100–150 g. Production ponds are prepared by the application of 20 tonnes/ha/year of cow dung or 10 tonnes/ha/year of chicken manure. Plankton density is judged by the colour of the water and fertilization is regulated accordingly. Fingerlings are stocked at 10 000/ha and the fish are fed on farm-made feeds consisting of a 7:3 mix of rice bran and groundnut oilseed cake, respectively. The feed is presented to the fish in feeding bags. Holes are punched into the bag and up to 20 kg of mixed feed is placed therein; this is then suspended on a pole in the water column (20–25 bags per ha of pond surface area). Feed is replenished once a day in the morning and the fish generally consume the feed in 2–3 hours. Ration size is determined by growth and the feed consumption rate.

The duration of the production cycle in these systems is 9–12 months and fish are harvested when rohu attain 1.5 to 1.75 kg and catla reach 2.0–2.5 kg (Figure 3). Production in these culture systems averages between 5 000–8 000 kg/ha/year, although production rates as high as 14 000–15 000 kg/ha/year have also been reported. Because farmers practise supplementary feeding it is difficult to assess the true feed conversion ratio. However, the apparent feed gain ratio is 2.0–4.5. Moreover, farmers intelligently resort to skilful on-farm feed management strategies. When fish are in an active growth phase during summer they feed protein rich oilcakes in a larger proportion (30–40 percent) (Figure 4). During the slow growth phase in winter and the monsoon season only rice bran fortified with a small proportion of oil cakes is fed to the fish. In this way feed expenditure is kept under control.

There have been some recent attempts to demonstrate (American Soybean Association) the use of extruded pellet feeds in freshwater fish culture in the state of Tamil Nadu (Suresh, 2007), though the results have not been adopted by the farmers.

Broodstock are fed with semi-moist dough feeds consisting of 15–20 percent dry fish powder (fishmeal), 10–15 percent rice flour, 20–25 percent groundnut cake and 15–20 percent pulses. The ingredients are finely powdered and mixed. Water is added (25–30 percent by weight) and the mixture is cooked, cooled and fed to the brood fish in the form of feed balls or meat mincer extruded spaghetti. The cost of cooking amounts to US$0.04–0.07/kg of feed. Fry in nurseries are fed a mixture of rice bran and oil cake (1:1 ratio) in powder form by broadcasting over the pond.

Carnivorous fishes such as *Clarias batrachus*, *Heteropneustes fossilis* and *Clarias gariepinus* are cultured in some areas in the north-eastern states. In the absence of hatchery reared seed, wild juveniles are caught and used. Carnivorous fish such catfishes (*Clarias batrachus* and *Heteropneustes fossilis*), snakeheads and the African catfish *Clarias gariepinus* are also reared in manured ponds and fed simple feeds such as fresh trash fish, animal by-products, poultry offal, silkworm pupae and kitchen waste. No attempts have yet been made to produce a formulated water stable pellet for carnivorous fish in India and this is simply related to the absence of an adequate demand.

FIGURE 3

Partial harvesting of carps from a farm in Thanjavur district, Tamil Nadu

Thanjavur is in the Cauvery delta and carp culture is practised fairly intensively in this area. The carps produced here are for local consumption and the fish usually fetch a good market price.

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FIGURE 4

Ingredients (groundnut cake, rice bran and maize flour) for preparing farm-made feed in a carp farm near Thanjavur district, Tamil Nadu

Freshwater carp farmers in India (particularly in Andhra Pradesh and Tamil Nadu) often resort to different on-farm feed management strategies. During summer, when carp are in an active growth phase they feed protein rich oilcakes in a larger proportion (30–40 percent). During the slow growth phase in winter and the monsoon season only rice bran fortified with a small proportion of oil cakes is fed to the fish. In this way feed expenditure is kept under control.

COURTESY OF P.E. VIJAY ANAND

3.2 Giant freshwater prawn

Two types of aquaculture practices are commonly used for the culture of giant freshwater prawn. One is monoculture of the prawn while the other is polyculture along with Indian major carps (catla and rohu). In monoculture the farmers stock up to 50 000 seed per hectare directly from hatchery. Whereas in the polyculture practice, the seed is stocked in nursery ponds at the rate of 150–200 PL/m^2 in semi-intensive method and 800–1 000 PL/m^2 in the intensive method (Vasudevappa 2001). During the nursery phase PL are fed with granular (starter grade) feeds of 35 percent protein that are commercially available and PL are grown to 3.0–5.0 g in about 60 days. These juveniles are stocked in grow-out ponds at 8 000 to 20 000 per hectare. Along with prawns, fingerlings (3–100 g) of catla and rohu are also stocked at 150 to 2 500/ha (Rao, Anandakumar and Sinha, 1999).

Prawn pond preparation includes ploughing of the substratum, application of lime and cattle manure at the rate of 500–5 000 kg/ha or poultry droppings at 2 000 kg/ha. Inorganic fertilizers are also used. Urea is applied at the rate of 5–50 kg/ha and single super-phosphate or di-ammonium phosphate at 18–25 kg/ha. Stocking of prawns or prawns and fish occurs after 10–15 days, when the water has taken on a light green or brownish colour. More than 60 percent of prawn farmers use nutritionally complete shrimp feeds, while the remainders use farm-made feeds, which generally contain 20–30 percent crude protein and cost around US$0.3–0.4/kg. As many as 18 different ingredients are used in prawn feeds, some of which are listed in Table 17. The farmers hire pelleting units for the manufacture of feeds. Prawns are fed 3–4 times per day at a rate of 2 to 5 percent of the body weight. Feed is normally broadcasted over the pond. The fish mainly feeds on the plankton naturally produced in the pond and hence no additional feeding is done. The fish grow to 1–2 kg in weight at the time of harvest.

Freshwater prawn ponds are normally stocked in July. After four months, when the prawns attain an average weight of 40 g, they are partially harvested every fortnight over a period of 4–6 months until the ponds are finally harvested. Prawn production levels, depending on stocking density, vary between 350–2 000 kg/ha/crop, whilst fish production varies from 250–2 500 kg/ha.

3.3 Penaeid shrimp

During the mid 1980s traditional shrimp farmers used a variety of single ingredient feeds such as clams, mussels, oysters, snails, trash fish, chicken offal and beef (Alagarswami and Ahamad Ali, 2000) or mixed *farm-made* feeds consisting of up to three or four ingredients such as dry fish powder, oil cakes (mainly groundnut), rice bran and cereals (wheat, rice or maize). Examples of some farm-made feeds are given in Table 16. The mixed farm-made feeds are cooked and presented as dough balls or in the form of "spaghetti", both in moist and dry form. These are made by extruding the cooked mix through a hand or electrically operated meat mincer. These practices have largely been phased out and replaced by the "made to order feeds or custom

TABLE 16
Examples of farm-made feed formulations used by shrimp farmers in various states of India during the mid 1980s

Ingredients %	State					
	Andhra Pradesh	Karnataka	Kerala	Maharashtra	Tamil Nadu	West Bengal
Dried fish powder	21.0	20.0	-	50.0	16.0	32.0
Clam meat	-	5.0	50.0	-	-	-
Squilla	-	-	-	-	16.0	-
Snail meat	-	-	-	-	20.0	-
Shrimp waste	20.0	-	-	-	-	-
Bone meal	20.0	-	-	-	20.0	-
Fish oil	1.0	-	3.0	-	-	-
Soybean oil	1.0	-	-	-	-	-
Soybean cake	20.0	-	-	15.0	-	-
Groundnut cake	-	15.0	30.0	10.0	-	-
Mustard cake	-	-	-	-	-	33.0
Rice flour	-	10.0	-	-	-	-
Rice bran	10.0	50.0	15.0	10.0	16.0	33.0
Wheat flour	-	-	-	10.0	-	-
Tapioca flour	6.0	-	-	-	10.0	-
Vitamin/mineral mix	1.0	-	2.0	5.0	2.0	2.0
Form of feed used/ presentation	Ball/pellet	Dry powder	Ball	Pellet	Ball/pellet	Dry powder
FCR	2.5–3.0	3.0	3.5	3.0–4.0	2.5–3.0	2.0–2.5
Production (kg/ha/crop)	500–700	700–900	700–900	700–900	700–900	400–5 000

Source: Nandeesha (1993)

made feeds" and commercially produced, nutritionally complete feeds. The "made to order feeds" are manufactured by small-scale feed manufacturers who custom make the feeds based on the individual formulations as well as the requirement of their clients. Over 20 of these small-scale feed millers operate in Andhra Pradesh alone. These feed manufacturers use mainly low-value dry fishmeal, mantis shrimp (*Squilla*), shrimp waste, peanut and soybean oilseed cake, crude fish oil, cereal flours and rice bran in addition to some low-cost additives such as lecithin, vitamins and mineral mixes (see Table 17 for list of feed ingredients) and orders of between 25 and 1 000 kg of feed are manufactured.

The manufacturer charges the cost of ingredients and a processing cost of US$58–70/tonne, with the total cost of feed ranging from US$0.3–0.56/kg. These custom made feeds normally have a protein content of 22–35 percent, FCRs ranging from 1.8–2.5:1 and with which production levels of 400–900 kg/ha/crop are attained. This shrimp feed manufacturing sector has proved to be highly beneficial to the small and marginal farmers who are not in a position to purchase large quantities of commercial feeds. Instead they can buy small quantities of feed and exercise their choice in the selection of feed ingredients.

Larger farmers and corporate companies who practise semi-intensive and intensive shrimp culture use nutritionally complete extruded pelleted feeds. These feeds are manufactured by commercial scale aquafeed-millers or are imported. There are ten feed mills (see Suresh, 2007) manufacturing nutritionally complete shrimp feeds in the country. Minimum and maximum inclusion levels used by commercial feedmills are shown in Table 18. The ingredients used by the commercial feedmills include fishmeal, squid meal, squid liver meal, shrimp meal, fish soluble, fish oil, squid oil, soybean meal, lecithin, cereal flour and other essential and proprietary additives. Most of the ingredients of marine origin are imported while the feed ingredients of plant origin are sourced locally (see also Suresh, 2007).

These extruded feeds have protein levels of 40–45 percent, FCRs of 1.2–1.5:1, cost between US$1.0–1.5/kg, with which production levels of 4–6 tonnes/ha/

TABLE 17

Ingredients used in the 'made to order' shrimp feeds, average inclusion levels and approximate cost. Inclusion levels are expressed in percent except otherwise indicated

Ingredient	Inclusion level (%)	Cost/kg (US$)
Sergisted shrimp (*Acetes*)	10.0	0.69
Pulverized dry fishmeal	15.0	0.58
Mantis shrimp (*Squilla*)	15.0	0.23
Silkworm pupae	3–5	0.19
Meat meal	3–5	0.28
Fish oil	1–2	1.39
Soybean meal	15.0	0.30
Groundnut cake	2–5	0.23
Ragi (millet)	2–5	0.20
Pearl millet	2–5	0.20
Rice bran	2–5	0.18
Maize gluten	5–6	0.25
Chicken egg	As per farmers desire	-
Dicalcium phosphate	0.8–1.0	0.93
Wheat flour	5–10	0.34
Calcium carbonate	0.1–0.15	0.46
Amino acid mix (methionine & lysine)	0.1–0.2	2.32
Vitamin mix	0.5–1.0	3.49
Zeolite	0.01	0.93
Feed probiotic	1.0 kg/tonne	23.25
Yeast extract (brewery residue)	1.0 kg/tonne	0.93
Preservative	0.001	-
Binder	0.8–1.0	3.94

TABLE 18

Common feed ingredients used in commercial shrimp feeds and their inclusion levels

Ingredient	Inclusion level (%)
Protein sources	
Fishmeal (imported)	25–40
Fishmeal (pulverized dry fish)	10–35
Squid meal	3–5
Sergisted shrimp (*Acetes*)	10–15
Shrimp/head meal	5–15
Mantis shrimp	10–15
Silkworm pupae	7–15
Soybean meal	15–30
Groundnut cake	10–25
Sunflower cake	10–15
Sesame cake	10–15
Mustard cake	10–15
Corn gluten	10–15
Lipid sources	
Fish oil	2–3
Lecithin	0.5–2.0
Carbohydrate/energy sources	
Wheat flour	10–30
Refined wheat flour	10–30
Rice flour	10–30
Rice bran	8–15
Tapioca flour	10–25
Binders	
Guar gum	1–3
Wheat gluten	3–5
Binder	0.5–1.0

FIGURE 5
Indigenous aerator used in a shrimp culture pond

Small and marginal shrimp farmers use indigenously assembled aerators which are less expensive than industrially made aerators. These locally made/assembled aerators are operated using diesel engines where electricity is not available at the farm site.

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FIGURE 6
Shrimp feed top-coated with additives by the farmer

As a common practice shrimp farmers in India coat the feed with different feed additives including probiotics, immunostimulants, vitamin C, fish oil and egg albumin through surface coating of the pellets. These feed additives are perceived by the farmers as feed attractant and growth promoter.

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crop are achieved. All these feeds are readily available in the market (for further detail see Suresh, 2007). The industrial feedmills produce a minimum of three grades of feeds namely, starter, grower and finisher. The shrimp feed industry has grown substantially over the last 15 years and the consumption of shrimp and prawn feeds has increased from 30 000 tonnes during the early 1990s to 193 500 tonnes in 2004 (see Suresh, 2007).

On-farm shrimp feed management campaigns are conducted regularly by different agencies in order to train shrimp farmers and to ensure that they use good management practices (GMP) for sustainable shrimp farming. These campaigns have been successful.

Prior to stocking, farmers ensure proper development of a natural food web (phytoplankton and zooplankton) in the pond through the application of organic manure and fertilizers. Shrimp seed (>PL_{20}) from hatcheries are acclimatized to pond conditions by adding water to the seed containers before they are stocked in ponds. Most commonly in the first two weeks external feed is not provided. Some farmers use a pre-starter powder which is broadcasted over the pond. The rate of feeding at this stage varies from 20 to 100 percent of the estimated biomass of the PLs. After two weeks the shrimp are fed with a starter grade feed (0.5 to 1.0 mm size) at the rate of 8–10 percent of the biomass. The daily ration is fed 3–4 times a day and feeding trays are used to monitoring consumption and to adjust the ration. Aerators for increasing dissolved oxygen in ponds are used as and when required (Figure 5). Small boats are used to broadcast the feed uniformly. By the time the shrimp reaches a harvestable size, the rate of feeding has gradually been reduced to 2–3 percent of biomass. A typical feeding schedule used in shrimp farms is given in Table 19.

Since the emergence of White Spot Viral Syndrome on Indian shrimp farms, water exchange procedures have changed radically. Farmers now change their water less often for fear of disease outbreaks. Water exchanges are done only when necessary and some farmers practise zero water exchange. In some areas farmers have resorted to the use of reservoir ponds, in which water is treated with chlorine prior to using it in the ponds. It is now also common practice for farmers to coat the feeds with probiotics and immunostimulants (Figure 6). Additional Vitamin C is often added through surface

TABLE 19
A typical feeding schedules used by shrimp farms in India at stocking densities of 5 and 10 PLs/m²

Week	Mean weight (g)	Expected survival (%)	Rate of feeding (% of body weight)*		Quantity of feed (kg/day)*	
			5/m²	10/m²	5/m²	10/m²
1	0.5	90	nil	-	nil	2.0
2	1.0	89	nil	-	nil	4.0
3	2.0	88	4.0	6.0	3.5	10.5
4	2.9	87	3.8	5.5	4.8	13.9
5	3.9	85	3.6	5.0	5.9	16.6
6	5.0	84	3.4	4.8	7.1	20.2
7	6.2	84	3.2	4.6	8.3	23.9
8	7.5	83	3.0	4.4	9.3	27.4
9	9.0	82	3.0	4.0	11.0	29.5
10	11.0	80	3.0	3.8	13.2	33.4
11	14.0	78	2.8	3.4	15.2	37.1
12	16.0	76	2.5	3.2	15.2	38.9
13	18.5	75	2.4	2.8	16.2	38.9
14	20.0	74	2.3	2.7	17.0	40.0
15	22.5	73	2.2	2.5	18.0	41.0
16	25.0	72	2.0	2.3	18.0	41.4
17	28.0	71	2.0	2.1	19.8	41.7
18	31.0	70	2.0	2.0	21.7	43.4
19	33.0	70	1.9	2.0	22.0	46.2
20	35.0	70	1.8	1.9	22.0	46.2

*The above figures are guidelines. The actual figures should be calculated by periodic sampling and recording the average weight and estimated survival.

Source: Ahamad Ali, Gopal and Ramana (2000)

coating of the feed pellets. Fish oil, egg albumin and gels are used for surface coating. In their anxiety to grow and harvest shrimp successfully farmers are often convinced/persuaded to use various other products, though there is no evidence to show that such products have any beneficial effect.

4. PROBLEMS AND CONSTRAINTS OF AQUACULTURE FEEDS AND FEEDING

4.1 Freshwater aquaculture

Suresh (2007) identified freshwater fish nutrition and feeding as the most important limiting factors for the sustainable development of aquaculture in India. The major constraints faced by carp farmers are problems related to the quality and cost of feed ingredients. Rice bran often contains excess rice husk and oilseed cakes contain an excess of seed shells and the use of commercially manufactured feeds is uneconomical. The constraints faced by carnivorous fish farmers are the supply, transportation, cost and storage of trash fish, poultry offal and silkworm pupae. In the absence of cold storage facilities they also face health risks in handling animal by-products.

Farmers also face constraints in farm-made feed preparation. Due to the lack of proper infrastructure, facilities and equipment and the high cost of fuel, many farmers do not cook the ingredients, resulting in wastage of feed and deterioration of pond water quality. Nevertheless, despite the drawbacks, farmers have demonstrated that Indian carps can be successfully farmed on a commercial scale through proper fertilization and skilful on-farm feed management strategies using locally available low cost feeds.

The most serious constraint facing the aquafeed manufacturing industry is the supply of indigenous marine ingredients and increasing prices of imported ingredients such as fishmeal. Moreover, there are no official prawn or shrimp feed standards. This puts farmers at a disadvantage as the feeds made by small-scale producers are often not formulated according to the nutritional requirements of the species and feeds are often made with poor quality raw materials.

4.2 Brackish-water aquaculture

As mentioned earlier, a total of 193 500 tonnes of shrimp feed are used annually. The major feed companies which produce nutritionally balanced feeds use high quality feed ingredients such as fishmeal, squid meal and other squid products, shrimp meal, fish soluble and fish oil, all of which are imported. The large animal and aquafeed manufacturing companies are exempt from customs duty on many of these imported raw materials.

The small-scale feed companies use dry trash fishmeal, shrimp head meal, shrimp meal, mantis shrimp meal and fish oil, but are facing increasing levels of competition from other users. The pulverized fishmeal used by most of these smaller companies is not of the desired quality and is often contaminated with shrimp head meal, mantis shrimp powder and sand (see Suresh, 2007). Moreover, the local fish oil hardly conforms to international quality standards and is often rancid. Farmers and the smaller feed producers are constrained by access to appropriate machinery when making shrimp feed in accordance with the required quality and water stability. At present, most of the feed producers use imported binders such as wheat gluten and polymethylolcarbamide, although some of the feed manufacturers use indigenously available guar gum.

Small and marginal shrimp farmers often get themselves into credit trap. They obtain feed and other inputs on a credit basis from the feed dealers with a buy-back arrangement upon which the farmer has to sell the harvest to the dealer. If there is a crop failure due to disease, the dealer advances the inputs on credit once again and the farmers have to clear their accumulated debt on harvesting the crop. In this process the farmer receives a lower price than on the open market. The farmer also loses his/her bargaining power and ends up paying a higher price for feed. Most of the larger feed companies can provide credit to farmers and wait for 3–4 months till when the shrimps are harvested for repayment. Smaller shrimp feed producers are unable to compete in this arena as they do not have the capital reserves to deal with crop failure. Moreover, there are no official feed standards for shrimp feeds in the country at present, as there are for other livestock feeds. This places the shrimp farmer at a serious disadvantage. Fluctuating prices of shrimp and stringent quality and food safety standards for shrimp on the global market have been pushing farmers to bankruptcy. With the present scenario, farmers are looking towards developing low cost, high quality feeds for shrimp farming in India so that the activity remains profitable and is environmentally sustainable.

5. RESOURCE AVAILABILITY AND EXPANSION OF THE AQUACULTURE INDUSTRY

Aquaculture provides the only alternative opportunity to supply India's growing demand for fish. In terms of land and water resources aquaculture can expand. However, the increasing demand for feeds and feed ingredients may restrict the development of the sector. Aquaculture production is expected to reach 6.282 million tonnes by 2020 (Table 20). To achieve this goal depends largely on an adequate nutrient resource base. The demand for organic manures is expected to rise to 190.66 million tonnes (Table 21) and approximately 200 000 tonnes of nitrogenous as well as phosphate fertilizers will be required. Given current fertilizer production capacity (19.42 and 2.41 million tonnes for nitrogen and phosphorus fertilizers, respectively during 2003–2004) (see Table 8) it was concluded that the availability of fertilizer will not constrain the expansion and development of the sector. However, there is going to be pressure on the supply of organic manures due to the increasing demand for organic food production, which is gaining popularity.

Freshwater fish culture is expected to continue using current culture and feeding practices. Hence, the projected requirements for rice bran and wheat bran will increase from 85 800 tonnes, which is currently used, to 163 020 tonnes (Table 22). This is

TABLE 20
Present (2004) and projected aquaculture growth by 2020 in India

Sector	Present (2004)			Projected (2020)		
	Area under aquaculture (thousand ha)	Production (million tonnes/year)	Growth rate (%)	Area under aquaculture (thousand ha)	Production (million tonnes/year)	Growth rate (%)
Freshwater fish culture	600	2.640	6.6	1 000	5.020	6.0
Freshwater prawn culture	42	0.035	-	80	0.066	6.0
Penaeid shrimp culture	150	0.115	-	250	0.236	7.0
Brackish-water fish culture	10	0.010	-	40	0.960	6.0
Total	802	2.800		1 370	6.282	

TABLE 21
Present (2004) and projected fertilizer requirements by 2020 in India

Fertilizer & manure	Average application (kg/ha/year)	Quantity used (thousand tonnes)	Total quantity required by 2020 (thousand tonnes)
I- Freshwater fish culture			
a. Nitrogen fertilizer	200	100	190
b. Phosphate fertilizer	200	100	190
c. Organic manure	20 000	100 000	190 150
II- Freshwater prawn culture			
a. Nitrogen fertilizer	45	1.6	3.05
b. Phosphate fertilizer	45	1.6	3.05
c. Organic manure	2500	86.6	164.50
III- Brackish-water shrimp culture			
a. Nitrogen fertilizer	15	1.5	2.25
b. Phosphate fertilizer	10	1.0	1.50
c. Organic manure	1250	125.0	187.50
IV- Brackish-water finfish culture			
a. Nitrogen fertilizer	NA	NA	3.92
b. Phosphate fertilizer			3.92
c. Organic manure			165.50

TABLE 22
Present (2004) and projected use of feeds and feed ingredient and the requirements by 2020 for freshwater aquaculture and marine shrimp culture in India

Major feed/feed ingredients	Present (2004) use per annum (tonnes)	Projected requirement per annum by 2020 (tonnes)
Freshwater aquaculture		
Rice bran & wheat bran	85 800	163 020
Oil cakes	5 980	11 370
Marine ingredients (for prawn feeds)	6 000	10 000
Others	2 600	4 940
Shrimp culture		
Formulated feed	193 500	307 500
Fishmeal	36 000	73 800
Squid meal	2 700	5 535
Shrimp meal	11 250	23 062
Mantis shrimp meal	15 000	30 750
Soybean meal	33 000	67 650
Cereal flour	30 000	61 500
Fish oil	4 500	9 225
Lecithin	750	1 537
Binders	1 500	3 075

possible since the projected requirement is only 3.5 percent of the currently available quantity of rice and wheat bran. Hence it can be assumed that the availability of rice bran and wheat bran will not constrain development.

The demand for oilseed cakes is likely to increase from 5 980 tonnes (current use) to 11 370 tonnes. The current local supply of oilseed cakes amounts to some 22.1

million tonnes per annum. The projected requirement for oil cakes for aquaculture in 2020 constitutes 0.06 percent of the current total supply. There are alternative feeds and feed ingredients which are not fully explored and exploited. Important among these are *Azolla* based aquaculture of Indian major carps and the use of duckweed for carp culture. Table 14 lists some of the non-conventional ingredients that need further exploration and exploitation.

Giant freshwater prawn culture is growing rapidly due to the availability of hatchery produced seed and improved economic returns. The sector is expected to expand to a production level of 55 000–60 000 tonnes per annum by 2020. Freshwater prawn feeds contain approximately 20–25 percent of animal ingredients, besides agricultural by-products such as oilseed cake and cereal bran. The expected increase in prawn production, particularly by smaller farms, will put pressure on the supply of dry trash fish and mantis shrimp meal. The poultry industry is the greatest competitor (Wood and Coulter, 1988; Ahamad Ali *et al*., 1995) for these ingredients. However, given the reduction in the inclusion rates of fishery products and by-products in poultry feeds it is reasonably safe to assume that the supply will meet the future demand of the aquafeed industry.

Shrimp culture is projected to grow at around 7–8 percent per annum to reach 236 000 tonnes by 2020. The projected feed requirements for this level of production are outlined in Table 22. The currently available total volume of marine ingredients used for animal feeds in India is in the region of 335 191 tonnes. The total projected demand for dry fish, shrimp meal, mantis shrimp meal by small-scale feed producers is in the region of 137 612 tonnes. The demand of the industrial scale feedmillers will continue to be met through imports. Under this scenario both the small-scale and the industrial animal feedmills will be able to supply the needs of the sector in future.

The demand for soybean meal, cereal flour and fish oil is approximately 67 650 tonnes, 61 500 tonnes and 9 225 tonnes, respectively. The soybean meal and cereal flour requirements can easily be met by domestic production. Fish oil will however be in short supply and there is a need to explore the replacement of fish oil with other edible oils especially with vegetable oils.

6. RECOMMENDATIONS FOR IMPROVED UTILIZATION OF FERTILIZER AND FEED RESOURCES AND SUGGESTED POLICY GUIDELINES

For aquaculture to develop in a sustainable manner, India requires focused attention on input needs such as fertilizers, feed and seed. With regard to the distribution of fertilizers, aquaculture should be brought under the same policy umbrella as the agriculture sector. Fish, prawn and shrimp farmers should be able to join co-operatives to improve and ease the supply of fertilizers. With regards to feeds, attention should be focused on the elimination of anti-nutritional factors that are present in certain oilseed cakes and on feed stability. Water unstable feeds lead to waste and water pollution. Farmers should be encouraged to use simple binders to enhance water stability of their farm-made feeds. This would lead to greater profitability and a reduction in nutrient loading. The available information on feed management and economic efficiency of freshwater fish production should be more actively promoted. Whenever possible and profitable, farmers should be encouraged to use extruded pellets to improve feed efficiency. Given the future projections for aquaculture, agriculture should be encouraged to produce crops that are suitable for inclusion into aquafeeds.

Shrimp aquaculture depends heavily on fishmeal and other marine products and the aquafeed industry is already in the grip of the fishmeal trap. To steer clear of this trap, the search for alternative protein sources to replace fishmeal must be aggressively pursued and the production of soybeans for aquafeeds should be actively promoted. Fishmeal in India is a scarce commodity. To improve the quality of the locally produced fishmeal and fish powder there is a need to focus on quality control. This can be achieved by improving the technologies for drying in order to eliminate sand and other contaminants. Similar measures are required to deal with mantis shrimp, shrimp waste and sergisted shrimp.

During the early 1990s some 690 000 tonnes of bycatch was dumped by trawlers per annum (Wood *et al*., 1992). There is good reason to believe that the situation has not changed much. At an average reduction rate of 23 percent the dumped trash fish during that time would yield approximately 158 700 tonnes of high quality fishmeal. The economic feasibility of on-board fishmeal plants should therefore be investigated.

To improve feed and nutrient utilization there is a need to pay attention to the following:

- investigate the improved utilization of high energy diets (Peisker, 2001);
- improve the digestibility of the current high energy aquafeeds through biotechnological innovations, such as exogenous digestive bio-enzymes, probiotics and solid-state fermentation of selected feed ingredients;
- develop more comprehensive feed management protocols to reduce wastage and to improve the utilization of available nutrients to improve FCRs and reduce environmental health risks; and
- pay greater attention to fish and shrimp health, food safety and environmental standards. This is particularly important with respect to consumer demands such as "green" products, the unacceptable practice of using trash fish as fish feed and the demand for fish and shrimp rich in polyunsaturated fatty acids to meet consumer preference (Rosenlund, 2001).

Globally, environmental issues are going to play a dominant role in how aquaculture will be practised in future. For aquaculture to develop in a sustainable manner in India, fish and shrimp must be produced with minimal environmental impact. For this reason processing technologies, feed formulation and feed management practices have to be improved to optimize apparent digestibility coefficients of the various ingredients.

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APPENDIX
Dietary nutritional requirement of shrimp species

A.1. Dietary nutrient requirements (percent dry matter unless otherwise indicated) of tiger shrimp and Indian white shrimp

Nutrients	Tiger shrimp	Indian white shrimp
Crude protein	35–46	30–43
Arginine	3.71	3.06
Histidine	0.69	1.52
Isoleucine	0.61	1.55
Leucine	1.03	2.98
Lysine	3.16	2.40
Methionine	1.24	1.05
Phenylalanine	1.70	1.64
Threonine	1.61	1.47
Tyrosine	0.51	-
Valine	2.06	2.78
Fat	3.5–8.0	6.0–9.0
Linoleic acid	0.05	-
Linolenic acid	0.10	-
Eicosapentaenoic acid	0.01	-
Docosahexaenoic acid	0.005	-
Lecithin	0.1–2.0	0.5–2.0
Cholesterol	0.5	0.5
Total energy (kcal/100g)	280–370	350–400
Calcium	2.0–2.5	0.5–0.6
Phosphorus	1.2–1.4	1.1
Potassium	0.7–0.9	1.3
Magnesium	0.08–0.15	Trace
Iron (mg/kg)	60–80	-
Zinc (mg/kg)	80–100	240
Manganese (mg/kg)	40–50	Trace
Copper (mg/kg)	8–10	13.6
Cobalt (mg/kg)	0.8–1.0	-
Iodine (mg/kg)	4–5	-
Chromium (mg/kg)	0.6–0.8	-
Selenium (mg/kg)	0.17–0.21	-
Riboflavin (mg/kg)	40	80
Thiamine(mg/kg)	120	100
Pyridoxine (mg/kg)	120	200
Pantothenic acid (mg/kg)	100	75
Niacin (mg/kg)	150	250
Folic acid (mg/kg)	5.0	-
Biotin (mg/kg)	1.0	-
Vitamin B_{12} (mg/kg)	<0.1	-
Choline chloride (mg/kg)	600	625
Inositol (mg/kg)	2 000	3 000
Vitamin C (mg/kg)	4 000	4 000
Vitamin D (mg/kg)	0.03–0.05	-
Vitamin E (mg/kg)	200	-
Vitamin K (mg/kg)	40	-
Vitamin A	3–6	-

Source: Alagarswamy and Ahamad Ali (2000)

Development of the aquafeed industry in India

A. Victor Suresh
Aqua Feeds: Formulation & Beyond
A3 Sanskriti Apartments, 17 and 18 Velachery Bypass Road, Velachery, Chennai 600 042
India

Suresh, A.V. 2007. Development of the aquafeed industry in India. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 221–243.

SUMMARY

India is the second largest aquaculture producing country after China. The current annual aquaculture production exceeds 2.47 million tonnes of fish, freshwater prawns and marine shrimp. Production of carps dominates Indian aquaculture with an annual production exceeding 2.11 million tonnes, while the total shrimp and prawn production is over 172 000 tonnes. The terrestrial and aquatic animal farming sectors are rapidly expanding and intensifying in India. However, industrial feed manufacturing in India still lags behind other rapidly developing economies in size and sophistication. The current level of industrial feed production for terrestrial livestock is estimated to be about 5 million tonnes, though requirements exceed 42 million tonnes. Similarly, aquaculture requires at least 2.59 million tonnes of manufactured feeds but, at present, only about 200 000 tonnes are manufactured. Semi-intensive and intensive carp and other freshwater fish production systems in India are predominantly based on farm-made feeds. An estimated 6.83 million tonnes of feed ingredients are used for producing farm-made feeds, while only 10 000 tonnes of industrially manufactured feeds are used in freshwater aquaculture. Preliminary data suggest that the use of manufactured feeds could bring about significant savings in carp production. Food conversion ratios could be reduced from 3 to 1:1 when manufactured feeds replace farm-made feeds. There are additional benefits associated with manufactured feeds in the form of cleaner ponds and less labour for feed preparation and feeding. The principal constraint to the use of manufactured feeds in fish production is the perception that such feeds are not cost effective. Once feed manufacturers and farmers realize that it is possible to produce profitably and use feeds in fish farming, the use of manufactured feeds will increase. It is likely that the use of manufactured feeds in freshwater fish farming will increase from the present 10 000 tonnes to at least 250 000 tonnes within the next five years.

The use of industrially manufactured feeds in Indian aquaculture started in the early 1990s when feeds were imported from Taiwan Province of China, Southeast Asia and the United States of America for shrimp production. Currently, India has more than sufficient capacity to produce adequate volumes of feed for freshwater prawn and marine shrimp farming. Annual production of prawn and shrimp feeds is around 190 000 tonnes against an installed capacity of around 500 000 tonnes per year. Other than in the traditional, extensive production systems in Kerala and West Bengal that are not designed to use feeds, industrially manufactured feeds are used in almost all prawn and shrimp farms in India. Falling prices of prawns and shrimps in the global market have meant lower profitability for the farmers and the high cost of feed has become a constraint. While market forces will no doubt correct this imbalance over a period of time, opportunities exist in research and policy-making to achieve efficiencies that would lower the cost of feed per unit of production.

There is an adequate domestic feed ingredient resource base for most of the animal feed requirements by the aquaculture and animal production sectors. For example, India produces 3.5 million tonnes of rice bran, the chief ingredient in fish feeds, which is sold at Rs 3 200/tonne (US$71.11). However, maize has to be imported to meet the needs of the poultry sector and fishmeal and marine oils are imported for the shrimp farming sector. Fortunately, India is one of the biggest exporters of soybean meal in the world and enjoys a competitive position as far as most aquafeed ingredients are concerned. However, the high import tariff imposed on feed additives is a constraint, although this will probably change with the implementation of global trade reforms.

1. INTRODUCTION

This report reviews the development of the aquafeed industry in India. It is principally based on secondary information and data derived from the published literature, unpublished reports and some primary data collected in the field. The report provides:

- a brief overview of aquaculture practices and farming systems, with production data (weight and value) of major species groups;
- an overview of the animal feed manufacturing sector including total compound animal feed production, production capacity and potential, feed manufacturing associations as well as the relevant regulations and controls;
- a review of availability, nutritional value and cost of feed ingredients including feed additives (e.g. vitamins, minerals, antioxidants and binders) including summary information on current feed and feed ingredient imports and exports;
- a summary of feed production for major species group and farming systems;
- a summary analysis of constraints on the use of commercially manufactured feed for small- and medium-scale aquaculture enterprises, including a comparative assessment of the economics of small-scale aquaculture based on industrially manufactured complete/semi-complete feed and farm-made feeds; and
- recommendations and suggested policy guidelines for improved utilization of industrially manufactured feed.

2. AQUACULTURE IN INDIA: A BRIEF OVERVIEW

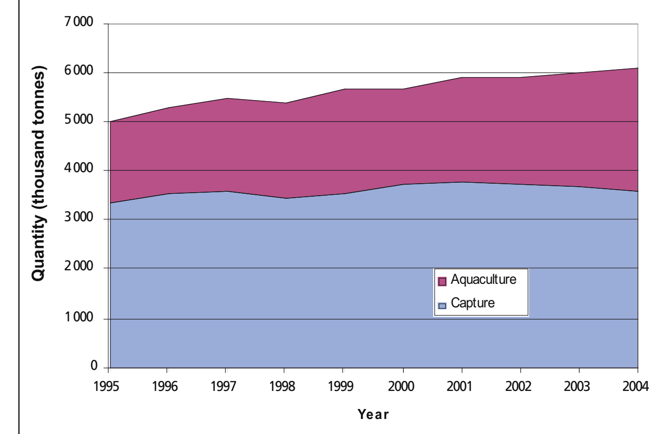
In 2004 India was estimated to have harvested about 6.09 million tonnes of aquatic products, mainly finfish and shellfish (FAO, 2006). This is slightly lower than the figures provided by Ayyappan and Ahamad Ali (2007), who estimated that India's total aquatic food production was 6.4 million tonnes in 2004 and that aquaculture contributed about 2.37 million tonnes of this production. The FAO data show that roughly 59.5 percent was from capture fisheries and the remaining 40.5 percent was from aquaculture. Figure 1 shows that the contribution by capture fisheries has almost stagnated at about 3.5 million tonnes in the last 10 years, whereas aquaculture has grown from 1.66 to 2.47 million tonnes during the same period. Ayyapan and Diwan (2004) predicted that Indian aquaculture would continue to grow at an average annual growth rate of about 8 percent in the next five years.

Freshwater aquaculture accounts for the bulk of production and amounts to around 2.34 million tonnes per year. In comparison, the average annual brackish-water and marine shrimp production over the last five years has been around 100 000–170 000 tonnes. Even though this represents only a small fraction of the total marine harvest in India, the proportional contribution to total value is high.

2.1 Freshwater aquaculture in India

As stated earlier, current freshwater aquaculture production in India is 2.34 million tonnes. Most of this production is attributed to carps which accounted for 90.5 percent of the total freshwater production in India (Table 1). In 2004, the three Indian major carps (catla, rohu and mrigal) contributed 59.7 percent, common carp 19.4 percent and the two Chinese carps (grass and silver carp) 11.3 percent to total freshwater production.

FIGURE 1
Aquatic food production in India from 1995 to 2004



Source: FAO (2006)

TABLE 1
Aquaculture production by species groups in 2004

Species groups	Tonnes
Indian major carps	**1 396 855**
Catla	467 962
Rohu	486 113
Mrigal	442 780
Chinese & common carps	**719 472**
Grass carp	100 641
Silver carp	165 084
Common carp	453 747
Snakeheads	29 949
Catfishes	42 160
Other fishes	108 958
Freshwater prawns	**38 965**
Monsoon river prawn	245
Giant freshwater prawn	35 720
Total freshwater aquaculture	**2 336 359**

Source: FAO (2006)

There are three broad types of carp farming systems in India (Table 2). The most traditional of the three are the stock-and-harvest systems, in which fish seed is the only input and in which the fish are totally dependent on natural productivity. This is practised in larger water bodies, particularly reservoirs. Based on current yields that range from 11 to 48 kg/ha in large-to-medium and small reservoirs, respectively (Nath and Das, 2004), the estimated total annual production of fish from these systems is about 90 000 tonnes. Currently, there is little scope for feed use in reservoirs and other extensive waterbodies. However, should cage culture in reservoirs ever become a reality in India, there is a vast potential for increasing fish production and feed use.

The second type of carp farming practice is generally referred to as low input, extensive culture. This is practised in a variety of waterbodies that may not necessarily have been excavated for fish farming. Examples are rice paddies and seasonally flooded pools. Fish are stocked at low densities (<5 000/ha) and the water may be fertilized with organic manures such as cow dung. A limited quantity of feed, in the form of crop residues, is provided. Yields typically range from 1 to 2 tonnes/ha/year. The production data are unreliable, but it is likely that at least 1 million tonnes are produced annually from this sector.

The third type is intensive pond culture in which fish stocking densities exceed 5 000/ha. The ponds are fertilized and the fish are fed, the yield normally exceeds 5 tonnes/ha/year. There are no reliable production data from this sector but it is likely that at least 750 000 tonnes are produced by intensive pond culture.

Carp culture in India has evolved over the past 50 years, with some regional disparities – predominantly from stock-and-harvest fisheries to more intensive forms of production. Stock-and-harvest fisheries and low-input, extensive pond culture of several species still exist in almost all parts of the country. A variety of farming systems including sewerage-fed aquaculture exist in states such as West Bengal. Intensification has mainly occurred in the southern states, particularly Andhra Pradesh, Karnataka and Tamil Nadu, and in the northern states of Punjab and Haryana. Carp farming is still predominantly polyculture, though there has been a decline in the use of Chinese carps, particularly silver carp. The poor eating quality of this species and difficulties in spawning this fish are cited as the reasons. Intensive farmers increasingly prefer catla and rohu as the only two species for carp farming because of their relatively high market value. Common carp is preferred in some areas (e.g. Karnataka). Other herbivorous species such as *Puntius* spp. are included with carps in the eastern states (Orissa and West Bengal).

TABLE 2
Summary of carp farming systems in India

System type	Inputs	Farm production (tonnes/ha/year)	Estimated national production (tonnes/year)
Stock and harvest in reservoirs	Fingerlings only	0.02–0.03	90 000
Rice paddy, seasonally flooded pools, temple ponds, water storage reservoirs for agriculture, sewerage-fed pools	Fingerlings, manure, occasional feeding with agricultural by-products and household waste	1.00–2.00	1 000 000
Ponds with proper embankments and drainage	Fingerlings, manure, systematic feeding with ingredients such as rice bran and oil seed residues	>5.00	750 000

Commercially successful intensification of carp culture started in the southern state of Andhra Pradesh in the mid- to late 1980s (Veerina *et al*., 1999). The intensification was characterized by:

1. an increase in the stocking density from 5 000 to about 8 000/ha;
2. a shift towards polyculture of Indian carps only and in particular catla and rohu at a ratio of 1:4-1:15;
3. establishment of effective nursery systems for the fry and advanced fingerlings. When fingerling and grow-out production cannot be synchronized, fingerlings are provided with a maintenance ration until they are needed. Compensatory growth is rapid and the fish reach 1.5–2.0 kg in one year;
4. their fertilization. Though ponds are large (10–20 ha), they are fertilized with poultry manure throughout the production cycle. Fertilization is well managed and farmers routinely sample pond water to observe plankton production (Figure 2) and add fertilizers when necessary; and
5. feeding practice. The fish are fed with de-oiled rice bran (90 percent) and groundnut and/or cotton oilseed cake. The feedstuffs are blended and packed in plastic bags with holes (Figure 3) and these are suspended in the ponds (Figure 4). Further details of the ingredients and feed composition are provided later in the report.

The market value of carps varies within and between states. West Bengal as a whole, and Kolkata in particular, is the biggest market for carps in India, where the current price varies from Rs 45 to 60/kg (US$1–1.3).[1] Similar prices are obtained in urban markets in the states of Punjab and Haryana. Andhra Pradesh is the biggest intensive carp farming area in the country. However, because marine fish are preferred here the market price for carp is considerably lower, at around Rs 26–30/kg (US$0.57–0.66), hence most of the fish are transported to the market in West Bengal. Intensive carp farming in Tamil Nadu occurs in the Cauvery delta region. Though also a coastal region, carp is readily accepted on the market and currently fetches around Rs 40–45/kg (US$0.9–1.0).

Carnivorous snakeheads, clariid and pangasiid catfish are also produced in India. Snakeheads, locally known as murrels, are cultured throughout the country in areas where seed availability is not a constraint. Snakeheads fetch a high market price

FIGURE 2
Sampling of pond water to check plankton density

Farmers of intensive carp culture system in Andhra Pradesh routinely sample ponds to determine plankton density and adjust the fertilization schedule accordingly.

FIGURE 3
Bags used for feeding of fish in intensive carp culture in India

The bags are packed with supplementary feed before placing them in the pond. Bag feeding method is commonly used in intensive carp culture in Andhra Pradesh. The bag has several holes through which the fish access the feed packed into the bag.

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FIGURE 4
Bag feeding method in intensive carp culture in India

Bags filled with feed are tied to bamboo poles placed at the edge or centre of ponds.

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[1] US$1.00 = Rs 44.00 (Indian Rupee, INR)

of Rs 120–180/kg (US$2.67–4.00). As air-breathing fish they are stocked at a high density; however the lack of seed supply, their high protein requirement, slow growth and susceptibility to disease constrain the expansion of murrel farming. Wet trash fish and poultry processing waste (mainly guts and heads) combined with rice bran and oil seed residues are fed to the fish.

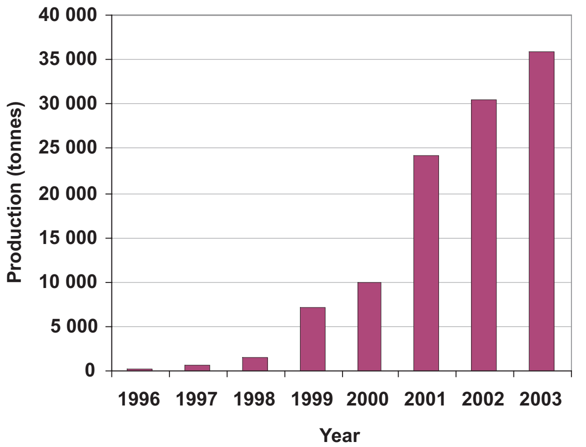
Catfish culture has recently expanded. While India has a number of endemic catfish species including *Clarias batrachus* and *Pangasius pangasius*, the faster growing African catfish, *Clarias gariepinus,* and sutchi catfish, *Pangasius hypopthalmus,* imported from Southeast Asia, have become the most widely farmed species in recent years. Legally these two species are not permitted to be farmed in India, hence production data are unavailable. Farmers typically use high stocking densities (>40 000/ha) and mixed feeds composed of rice bran, oilseed cake residues, kitchen waste, poultry processing waste and others. The fish grow to 1 kg within six months.

India is one of the few countries in Asia without tilapia in aquaculture. *Oreochromis mossambicus* was first introduced to India some 50 years ago and the species has now been established in reservoirs and lakes throughout the country. Owing to its unpleasant looking dark skin and peritoneum pigmentation, it does not have a broad market appeal and is considered to be a pest species in capture fisheries and aquaculture. Farming trials with red hybrid tilapia showed that the hybrid fish was well accepted by the market. The introduction of species into India requires an exotic species import permit and importers have to comply with quarantine requirements. Currently there is an initiative to introduce Nile tilapia (*O. niloticus*) into India, although there are unconfirmed reports that *O. niloticus* and the genetically improved farm tilapia (GIFT) have already been introduced via Bangladesh into West Bengal. The prospects for tilapia farming in India are good once appropriate candidate species have been introduced.

Extensive freshwater prawn farming has been practised for many years in floodplains and rice paddies in West Bengal and Kerala. Semi-intensive prawn farming only commenced in the mid-1990s in Andhra Pradesh when marine shrimp farming was severely affected by white spot syndrome virus (WSSV). Prawn farming was also facilitated by the available shrimp farming infrastructure. The species of choice is the giant freshwater prawn (*Macrobrachium rosenbergii)* that is locally and incorrectly referred to as “scampi”. Prawns are produced in ponds both under monoculture and polyculture conditions with Indian major carps. Grow-out stocking densities range from 0.5 to 2.5 prawns/m^2 in polyculture and 1 to 5/m^2 in monoculture and the grow-out period is 6–8 months. Average pond production is about 600 kg/ha; however, well-managed ponds produce up to 2 tonnes/ha/crop cycle. Freshwater prawns (average weight of 50 g) fetch approximately Rs 225/kg (US$5.10).

Prawn production in Andhra Pradesh, particularly in the district of Nellore, grew rapidly from 1996 to 2002 and this area now contributes approximately 80 percent of the country’s total prawn production. Low rainfall, disease problems during seed production and grow-out and lower export prices significantly affected prawn production in this district in 2003–04. This has been compensated for by increased production from other areas in Andhra Pradesh and elsewhere (Figure 5). India produces an estimated 25 000–30 000 of

FIGURE 5
Freshwater prawn production in India from 1996 to 2003



Source: Marine Products Export Development Authority brackish-water shrimp in inland waters (Figure 6), mainly in the districts of East and West Godavari in the state of Andhra Pradesh. The production systems, methods and feeds are not considerably different from those used in coastal waters (see below for details).

FIGURE 6
Brackish-water shrimp production in inland waters

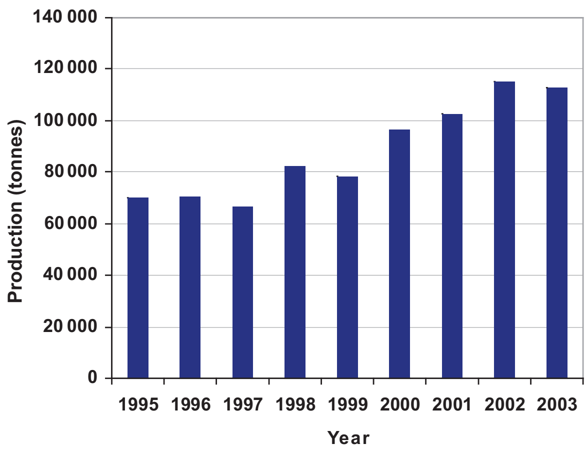
The pond represents low salinity (<5 ppt) systems in the Godavari and Krishna districts of Andhra Pradesh. Though trench-type ponds in a coconut grove as shown here are atypical, it is common to find shrimp ponds coexisting with rice paddy fields and coconut groves in the area.

2.2 Brackish-water and marine aquaculture

India's brackish-water and marine aquaculture sector produces only marine shrimp, mainly black tiger shrimp, *Penaeus monodon,* and smaller proportions of Indian white shrimp, *Fenneropenaeus indicus,* and Pacific white shrimp, *Litopenaeus vannamei.* Production of marine fishes, including Asian seabass/barramundi (*Lates calcarifer*), is negligible.

Extensive shrimp farming has been practised in India, particularly in Kerala and West Bengal, for several decades. Semi-intensive farming emerged in the late 1980s and grew rapidly in the early 1990s (Figure 7). The outbreak of WSSV stemmed the sector's growth in 1995. The sector was also affected by the Indian Supreme Court's decision to ban intensive and semi-intensive aquaculture practices within 500 metres of the high tide mark. Subsequently, the sector has experienced a revival and total production in 2004 reached approximately 116 000 tonnes. Recent setbacks to the sector include (i) imposition of anti-dumping duty on shrimp exported from India to the United States of America; (ii) low prices of shrimp due to global oversupply and anti-dumping duty; and (iii) the 2004 tsunami that affected hatcheries and farms in Tamil Nadu. WSSV still persists and new problems such as loose shell syndrome threaten the profitability of the sector. Loose shell syndrome is a unique disease problem in India that results in severe atrophy of the muscles. The etiology of the problem remains largely unknown, although a number of factors such as blue-green algae and poor pond bottom are thought to be causative factors.

FIGURE 7
Marine shrimp production in India from 1993 to 2003



Source: Marine Products Export Development Authority

There are three types of shrimp farming systems in India, i.e. traditional extensive, modified extensive and semi-intensive (Table 3). Traditional and extensive farmers in Kerala and West Bengal use large (>5 ha), irregular shaped ponds that are filled during flooding or through tidal exchange. Stocking densities are low (<5 PLs/m^2) and shrimps are either fed with farm-made feeds or receive no food at all. Typical yields are in the range of 200–400 kg/ha/crop cycle. There are no reliable estimates of production from these systems. Production in West Bengal and Kerala amounts to approximately 36 000 tonnes of shrimp and it is estimated that some 28 800 tonnes are produced in extensive systems.

TABLE 3
Summary of shrimp farming systems in India

System type	Inputs	Farm production (tonnes/ha/cycle)	Estimated national production (tonnes/year)
Traditional, extensive	Post-larvae/juveniles (hatchery or wild source), 2–5 animals/m²; farm-made feeds or no feeds	<0.5	30 000
Modified, extensive	Hatchery-produced post-larvae, 5–10 animals/m²; manufactured feeds	1.0-–1.5	50 000
Semi-intensive	Hatchery-produced post-larvae, 15–20 animals/m²; manufactured feeds	>2.0	30 000

Manufactured feeds are used in the other two shrimp farming systems. In semi-intensive systems, stocking densities exceed 15 PLs/m² and yields exceed 2 tonnes/ha/crop cycle. In the modified extensive systems, stocking densities are in the range of 7–10/m² and yields are about 1.0–1.5 tonnes/ha/cycle. Typical pond size is in the range of 0.8–1.0 ha each.

There are two distinct shrimp cycles (crops) in India. The first cropping starts in February/March and ends in May/June. The second cropping starts in August/September and ends in November/December. Typically, the first crop produces a higher yield than the second crop. Better water quality following the 2–3 months "between crop holiday" is cited to be the reason for such a difference. However, in recent years and with better management, this is becoming less common. The average duration of each crop cycle is 130 days. The average size of shrimp at harvest is 25–30 g and the farm-gate price of shrimp in the 25–30 g range varies between Rs 210 and 280/kg (US$4.88–6.22).

3. THE ANIMAL FEED MANUFACTURING SECTOR IN INDIA

The farm animal population of India in 2003 was estimated to be about 974.01 million (see Table 4). It is further estimated that in 2003 India produced a total of 5.98 million tonnes of meat, 88 million tonnes of milk and 40 billion eggs. Despite this large volume from the livestock sector, animal production in India is largely comprised of small- and medium-size farming enterprises. Most of the feeds used for animal production consist of natural pasture, farm-made feeds and some measure of scavenging. In comparison with other developed nations and fast-developing economies of the world the feed manufacturing industry is in the early stages of development.

The current volume of compounded feed production for the dairy, poultry and aquaculture sectors is about 5 million tonnes (CLFMA, 2005). It has been estimated that India would require about 42 million tonnes of balanced feed if livestock farming were to be primarily feed-based. By 2010, this demand is expected to increase to about 60 million tonnes (CLFMA, 2005). Table 5 summarizes the current production and estimated demand for feeds.

- **Dairy cattle.** The dairy cattle industry in India, though the largest in the world in terms of number of cows and milk production, is highly fragmented and widely distributed throughout the country, and is in the hands of millions of small farmers. Most farmers mix their own feed formulations and rely on

TABLE 4
Farm animal population of India in 2003

Species	Number (million)
Cattle	185.18
Buffalo	97.92
Small ruminants	185.83
Pigs	13.52
Other draught animals	2.55
Poultry*	489.01
Total	**974.01**

*Poultry population may have been underestimated. The Compound Livestock Feed Manufacturers Association (CLFMA) estimated that there were 150 million layer birds and 650 million broiler birds in 2003.

Source: Directorate of Economics and Statistics, Ministry of Agriculture (2003).

TABLE 5
Demand and current production of animal feeds in India (million tonnes)

Sector	Feed demand	Current feed production	Information source
Dairy cattle	45.00	2.00	CLFMA
Poultry, broiler	6.21	3.00	CLFMA
Poultry, layer	8.13	Not significant	CLFMA
Aquaculture, fish	2.31	0.01	Author
Aquaculture, prawn	0.27	0.19	Author

grazing or stall-feeding, using crop residues. Owing to the poor genetic make-up of the stock and management practices, use of manufactured feed may not improve productivity. Experts consider that manufactured feeds would be best utilized for only about 10–15 percent of dairy cattle in India that are cross-bred and optimally managed. The potential demand for dairy cattle feed is estimated at 45 million tonnes, assuming that only 50 percent of milk production in the country is from cattle that are fed manufactured feeds (CLFMA, 2005). The current estimated production of cattle feed is about 2 million tonnes indicating the high potential for the animal feed manufacturing industry. The major markets for dairy cattle feeds are Punjab, Haryana, Uttar Pradesh, Gujarat, Maharashtra, Karnataka, Kerala, Tamil Nadu and Andhra Pradesh.

- **Poultry.** Over the last decade, consumption of broiler meat has grown at an annual rate of almost 15 percent. The broiler production sector is technologically advanced, relies on balanced feeds and uses most of the animal feeds manufactured in India. Nearly 3 million tonnes of manufactured feeds are used by the sector. CLFMA (2005) reported that the feed requirement for the broiler sector was 6.21 million tonnes in 2004, while some 8.13 million tonnes are required for layers. Increased use of manufactured feeds in the poultry sector is constrained by cost.
- **Aquaculture.** See later.

Table 6 provides a summary of manufactured feed types, feed composition and costs of broiler feeds and various aquafeeds. The data suggest that feed costs as a percentage of market price for broilers and carps are quite similar. However, better resource efficiencies are possible if carps are fed on manufactured feeds (see later for further discussion). Prawn and shrimp feeds are more expensive than other feeds but, because of the high price of shrimp and prawns, production is relatively cost effective.

TABLE 6
Type of broiler and aquafeeds manufactured, composition and their cost

Animal	Broiler	Carp	Prawn	Shrimp
Type of feed	**Pellet**	**Mash**	**Pellet**	**Pellet**
Proximate composition				
Crude protein (%)	18	20	28	40
Crude lipid (%)	5.5	2.0	4.0	6.0
Crude fibre (%)	4	15	4	3
Costs				
Unit cost of feed (Rs/kg)	12	4	28	42
Unit cost of feed (US$/kg)	0.27	0.09	0.64	0.95
Feed conversion ration (FCR)	1.8	3.5	2.5	1.6
Feed cost/kg of animal produced (Rs)	21.6	14.0	70.0	67.2
Feed cost/kg of animal produced (US$)	0.49	0.32	1.59	1.53
Market size (g/animal)	2 000	1 000	70	33
Time to market size (day)	40	365	180	140
Sale price (Rs/kg)	40	30	270	250
Sale price (US$/kg)	0.91	0.68	6.14	5.68
Feed cost (% of sale price)	54.00	46.67	25.93	26.88

The Compound Livestock Feed Manufacturers Association (now simply known as CLFMA) is the only association that is widely recognized by the feed industry. Nearly 50 percent of manufactured feed in India is produced by members of the association. CLFMA has recommended quality norms for various livestock feed (Appendix, Tables A.1 and A.2). The Bureau of Indian Standards has also recommended specifications for various livestock feeds (Appendix, Tables A.3 and A.4). The Marine Products Export Development Authority (MPEDA) has similarly prescribed norms for marine shrimp feeds (see later for more detail). These standards and quality norms are adopted on a voluntary basis and are not enforceable.

4. AVAILABILITY OF FEED INGREDIENTS

India is primarily an agricultural economy and is one of the biggest producers (Table 7) of rice, wheat and many oilseeds, including soybean.

The broad agricultural base provides coarse grains, grain by-products (brans), and oilseed cake or meals for the manufacture of animal feeds. Ayyappan and Ahamad Ali (2007) provided a detailed estimate of agricultural products and by-products that could be used in animal feeding. CLFMA (2005) estimated the feed resources that are currently available from domestic agricultural production for livestock feeding (see Table 8).

In addition to by-products from crop production, India also produces some animal by-products such as meat and bone meal, blood meal, feather meal, fishmeal, fish oil, *Squilla* meal and shrimp waste meal. Production volumes of terrestrial animal proteins are not known. Ayyappan and Ahamad Ali (2007) estimated that nearly 340 000 tonnes of marine animal proteins are potentially available for feed use in India. India produces nearly 4 million tonnes of soybean meal a year, of which about 65 percent (2.6 million tonnes) is exported mainly to the Republic of Korea, Japan, Thailand, Indonesia, Malaysia, Viet Nam and the Philippines.

Given the current estimated feed requirement of 42 million tonnes, the feed resource base is perhaps just sufficient to meet the requirements. Indian international trade in animal feed ingredients is rather small except for maize and soybean meal. India imports maize when local production is not sufficient to meet domestic demand. Concerned about the economic effects of cheaper subsidized maize produced in western countries, particularly the United States of America, on domestic maize, India imposed a tariff of 15 percent on the first 500 000 tonnes of maize imported into the country. Imports above 500 000 tonnes attract a tariff of 65 percent. Import tariffs for major feed ingredients in India are listed in Table 9.

India imports fishmeal primarily for use in shrimp feeds. Small quantities may also be used in poultry and freshwater prawn feeds. India is not considered to be a significant importer of fishmeal or any other animal by-product. The total import of marine and animal by-products into India is unlikely to exceed 10 000 tonnes per year. There is an official ban on the importation of animal and poultry by-products due to fear of introduction of pathogenic factors responsible for bovine spongiform encephalopathy (BSE) and highly pathogenic avian influenza (HPAI), respectively.

TABLE 7
Estimates of agricultural outputs in 2003

Commodity	Quantity (million tonnes)
Rice	87.0
Wheat	72.0
Corn (maize)	14.7
Pearl millet *(bajra)*	11.8
Sorghum *(jowar)*	7.3
Finger millet *(ragi)*	2.0
Barley	1.3
Pulses	15.2
Soybean	5.5
Groundnut	8.3
Rapeseed/mustard seed	5.8
Sunflower	1.0
Cassava	6.0

Source: Hindu Survey of Indian Agriculture (2004).

TABLE 8
Available resources for animal feeds in 2004

Commodity	Quantity (million tonnes)
Oilseed cake and meals	15.76
Brans	13.26
Coarse grains*	5.74
Others	0.53
Total	**35.32**

*Coarse grain production may have been underestimated considering the fact that nearly 7.0 million tonnes of domestically produced maize is used by the feed industry.

Source: CLFMA (2005).

Ingredients and additives, imported and of domestic origin, do not require any form of registration in India, although the Ministry of Agriculture now requires an import certificate for all animal feed ingredients and finished feeds. The requirements vary from ingredient to ingredient and are not standardized. Unrealistic requirements are imposed from time to time, for example, the requirement that all fishmeal is free of WSSV. The certification process is considered by many in the feed industry to be a trade barrier.

Table 10 presents a list of ingredients that are commonly used in feed manufacturing in India and their typical nutritive composition and price. Because of their importance in aquafeeds, several of the available ingredients are discussed in greater detail below. Complementary information on the availability of an ingredient for and use in aquafeeds may be found in Ayyappan and Ahamad Ali (2007).

1. **Rice bran.** India produces 3–3.5 million tonnes of rice bran annually. Full-fat rice bran or rice polish is used for the extraction of rice bran oil and is therefore relatively expensive for use in feeds. If the oil is not extracted or the polish is not heat treated, the oil becomes rancid and the quality of the bran is reduced. De-oiled rice bran is the most important ingredient in carp feeds and is also used in prawn feeds. The quality of rice bran varies considerably. Mixing of rice husks with the bran is a serious quality issue. This can be detected by the ash and fibre content of the bran. High ash and fibre contents are indicators of poor quality. The relatively high level of protein and starch in rice bran makes it a valuable feed ingredient.
2. **Coarse grains.** Coarse grains are not used widely in Indian aquaculture. However, they have a high nutritive value in relation to cost, particularly in fish feeds. Maize, sorghum, finger millet and broken rice are good sources of starch. Once extrusion becomes more widely adopted in aquafeed production, the use of coarse grains will increase.
3. **Soybean meal.** Soybean meal with hulls (44 percent crude protein) and de-hulled soybean meal (48 percent crude protein) are available in large quantities in India. Currently, these products are used only in shrimp and prawn feeds. Fish farmers do not use soybean meal due to its high cost. However, once fish feeds are commercially manufactured, the use of soybean meal will increase.
4. **Groundnut cake.** Mechanically extracted groundnut cake has been traditionally used for the feeding of fish. Solvent extracted groundnut cake is now more commonly available on a commercial scale. Due to concerns about mycotoxins, groundnut cake is not used in shrimp feeds.

TABLE 9
Import tariffs (%) on feed ingredients imported into India (effective as from 24 August 2005)

Item	Basic duty	Counter veiling duty	Cess	Total
Fishmeal	5	0	0.10	5.10
Other marine protein meals and by-products*	30	0	0.60	30.60
Terrestrial animal protein by-products	30	0	0.60	30.60
Bran, rice (raw or de-oiled)	15	0	0.30	15.30
Bran, other grains (maize, wheat, etc.)	30	0	0.60	30.60
Residues of starch manufacturing**	30	0	0.60	30.60
Oilseed cakes and solid residues from oil extraction	15	0	0.30	15.30
Concentrates for feed preparation	30	0	0.60	30.60
Compounded feeds	30	0	0.60	30.60
Brewers' yeast	30	16	0.92	46.92
Cholesterol	15	16	0.62	31.62
Lecithin	15	16	0.62	31.62
Monocalcium phosphate	15	16	0.62	31.62

* Includes fish solubles, hydrolysate, etc.
** includes wheat gluten

5. **Cotton oilseed cake.** Solvent-extracted cottonseed cake is used in fish feed.
6. **Other oilseed residues.** Oil cakes of sunflower, coconut (copra meal), sesame and rapeseed are presently not commonly used in aquafeeds. These have high potential for use in fish feeds because of their low cost relative to nutritive value.
7. **Residues of starch manufacturing.** Locally produced maize gluten meal has now become available in India. Its potential for use in aquafeeds, especially shrimp feeds, is good due to its high nutritive value relative to cost. Wheat gluten is only available in small volumes. However, significant quantities are imported from Europe and China for use in the food industry. It is used in small quantities (<2 percent) in shrimp feeds as a binder.
8. **Wheat flour.** This ingredient is used only as a binder in pelleted shrimp and prawn feeds. India is one of the world's largest wheat producers and processors. Second-grade wheat flour, which is only marginally fit for human consumption, is used in animal feeds. Indian wheat has a low wet gluten index (<28 percent) relative to the ideal index for shrimp feed pelleting (32 percent).
9. **Fishmeal.** The shrimp feed industry mainly uses premium grade (prime or super prime) fishmeal imported from Chile or Peru. There are two types of locally available fishmeal, one of which is produced mostly from oily, small-pelagic fish such as sardines and mackerel. Typically, the fish are cooked and pressed to extract the oil. The press cake is then dried in a flame drier to produce a meal of about 55 percent crude protein. The factories may also use species such as leognathids and carangids. The meal has high ash levels. The other is made from fish that is unfit for human consumption. This fish is sun-dried and ground for use in feeds. The meal has high levels of ash and silica (the latter originating from the sand on which the fish are dried). Sun-dried meals are not commonly used in aquafeeds, but find use in poultry feeds. The factory-produced local fishmeal is used in prawn feeds. Most fishmeal factories are located on the west coast of India.
10. **Marine by-product meals.** Shrimp head and shell meal are produced by cooking and drying or simply drying shrimp processing waste. Clam and other mollusc meals are made by simple cooking, drying and milling methods. A small quantity of squid meal is produced and exported from India. Squid liver paste and meal and fish solubles are imported from the Republic of Korea and the Americas, respectively. Small quantities of fish hydrolysates are imported from Europe.
11. **Yeast.** Yeast is used in shrimp feeds. Currently, most of this product is imported from Brazil in the form of spray-dried, molasses yeast. The large brewing and distilling industry in India is not yet adequately organized to supply yeast and other brewery/distillery by-products.
12. **Fats and oils.** Fish and squid oils are primarily used in shrimp and prawn feeds. Squid oil is imported from the Republic of Korea, while fish oil is imported from the Americas. Crude fish oil is produced locally, but the method of production leads to poor quality oil. The presence of a high level of peroxides and free fatty acids prohibits their wider use. Soya lecithin is produced locally and used in shrimp and prawn feeds as a source of phospholipids. Indian manufacturers of lecithin supply only the dark, viscous lecithin variety. The lecithin, however, matches the phospholipid content (at least 65 percent) of imported liquid lecithin products. The meals produced from solvent extraction have less than 1 percent residual oil. Commercially manufactured fish feeds therefore require supplementation with fats and oils as a source of essential fatty acids and energy. The possibility of using crude forms of or by-products of soybean, palm and other edible oils in fish feeds requires investigation.

Table 11 presents a list of micronutrients and non-nutritive feed additives that are commonly used in feed manufacturing in India. Most preservative and mineral feed additives are now locally manufactured.

TABLE 10

Composition and price of aquafeed ingredients commonly available in India

Ingredient	Typical composition (percent as fed basis)				Typical price/tonne	
	Crude protein	Crude lipid	Crude fibre	Ash	Indian Rs	US$
Grains						
Finger millet	6.5	1.2	6.0	7.0	3 500	77.78
Sorghum (white)	8.0	2.5	3.0	2.8	5 000	111.11
Maize	8.5	3.5	2.0	1.9	6 000	133.33
Broken rice	8.5	0.4	0.6	0.8	7 000	155.56
Wheat flour	11.0	0.4	0.1	0.7	10 500	233.33
Grain by-products						
Wheat bran	12.8	3.2	11.1	8.4	5 000	111.11
Rice polish	13.0	15.8	6.6	9.8	5 500	122.22
Rice bran, de-oiled	15.2	0.2	17.0	10.1	3 200	71.11
Corn gluten meal	61.2	2.2	1.5	1.0	12 500	277.78
Wheat gluten	80.0	0.8	0.1	0.8	46 000	1022.22
Oilseed residues						
Copra meal (solvent extracted)	23.4	1.2	13.0	8.0	6 500	144.44
Sunflower meal (solvent extracted)	28.2	0.6	16.0	7.2	5 000	111.11
Cotton seedcake (solvent extracted)	36.8	2.5	9.8	6.2	7 500	166.67
Rapeseed meal (solvent extracted)	37.0	0.85	6.7	8.3	6 500	144.44
Soybean meal, 44% (solvent extracted)	44.5	1.6	6.0	8.0	11 400	253.33
Soybean meal, 48% (solvent extracted)	49.0	1.6	4.9	7.3	13 400	297.78
Groundnut cake (solvent extracted)	47.0	0.5	6.0	7.0	9 500	211.11
Animal by-products						
Fish soluble	26.0	4.0	NA	12.0	28 000	622.22
Shrimp meal	44.0	7.2	15.2	25.0	14 000	311.11
Squid liver powder	47.5	21.2	1.0	4.6	26 000	577.78
Fishmeal, local	57.8	10.9	NA	17.9	21 000	466.67
Fishmeal, imported	68.0	8.9	NA	13.0	33 000	733.33
Single cell protein						
Yeast	37.0	0.4	0.1	5.0	26 000	577.78
Oils and fats						
Fish oil, imported	NA	100.0	NA	NA	32 000	711.11
Fish oil, local	NA	100.0	NA	NA	26 000	577.78
Soy lecithin	NA	100.0	NA	NA	38 000	844.44

TABLE 11

Additives and other components used in the aquafeed industry in India

Additive/microingredient	Composition/details	Typical price/kg		Imported/local
		Indian Rs	US$	
Cholesterol	95 percent purity, used in shrimp feeds	2100	46.67	Imported
Mould inhibitor	Mixture of propionic acid and other organic acids and salts	100	2.22	Imported and local
Antioxidant	Mixture of BHT, BHA, ethoxyquin, etc	160	3.56	Imported and local
Pellet binder	Modified urea formaldehyde	120	2.67	Imported
Monocalcium phosphate	21-23% phosphorus	55	1.22	Imported
Dicalcium phosphate	18% phosphorus	16	0.36	Local
Limestone powder	Mostly used as a filler	2	0.03	Local
Mineral premix	Typical micromineral premix for fish feeds	22	0.49	Local
Salt	Feed grade	1	0.02	Local
Potassium chloride	KCl 50%	20	0.44	Local
Magnesium sulphate	$MnSO_4$ 31%	15	0.33	Local
Vitamin premix	Typical premix for fish feeds, without Vitamin C	220	4.89	Imported and local
Choline chloride		40	0.89	Imported
Vitamin C, coated	35% active ascorbic acid	360	8.00	Imported
Inositol		400	8.89	Imported

5. AQUAFEED PRODUCTION

It has been estimated that there is a need for approximately 2.59 million tonnes of aquafeeds in India (Table 12), although currently only some 200 000–250 000 tonnes are industrially manufactured. FCRs using farm-made feeds are 2–3 times higher than those achieved with manufactured feeds. On this basis, it was estimated that about 7.11 million tonnes of feed ingredients are used for the production of aquafeeds in India.

5.1 Feeds for freshwater fish farming

Almost all freshwater fish in Indian aquaculture are raised on farm-made feeds. Industrially manufactured feeds for carps are marketed by one major feed company (Godrej Agrovet Ltd) in Andhra Pradesh, Punjab and Tamil Nadu, on a trial basis. Limited experimental results are available, but at least one trial with grass carps indicates that FCRs of less than 1 are possible with manufactured feeds. The total volume of manufactured feeds sold for freshwater fish culture is estimated to be 10 000 tonnes/year.

As shown in Table 12, an estimated 6.83 million tonnes of ingredients are used to make farm-made feeds for fish production. Of this volume, at least 3 million tonnes are used to produce farm-made feeds for intensive carp production. In the Kolleru area of Andhra Pradesh, some 1.8 million tonnes of ingredients are used for the manufacture of farm-made carp feeds.

De-oiled rice bran is the major ingredient of all fish feeds in India and is used either singly or in combination with other ingredients. In the Cauvery delta, maize is ground and mixed with rice bran and groundnut cake to feed carps. The typical ratio of mixing is 2:1:1 of rice bran, maize and groundnut cake. In Andhra Pradesh, one or more of the following seven ingredients are mixed with rice bran to feed carps: rice polish, broken rice, groundnut cake, cottonseed cake, sunflower cake, meat meal and soybean meal. Veerina *et al*. (1993) observed that a combination of groundnut oilseed cake and rice bran was used by about 75 percent of farmers in the Kolleru area. A more recent survey indicated that the majority of farmers use a blend of rice bran, groundnut oilseed cake and cotton oilseed cake. The formulation and proximate composition of this feed are shown in Table 13.

TABLE 12
Estimated feed requirements based on aquaculture production in India in 2004

	Production (tonnes)	**Type of Feed**	**Current FCR**	**Current volume of feed use** (tonnes)	**FCR of manufacured feed**	**Potential volume of manufactured feed** (tonnes)
Fish						
Carps	2 026 327[1]	Farm-made[2]	3	6 078 981	1.0	2 026 327
Snakeheads	29 949	Farm-made	5	149 745	2.0	59 898
Catfishes	42 160	Farm-made	4	168 640	1.5	63 240
Other fishes	108 958	Farm-made	4	435 832	1.5	163 437
Total fish feeds				6 833 198		2 312 902
Crustaceans						
Freshwater prawns	38 965	Manufactured[3]	1.6	62 344	1.6	62 344
Penaeid shrimp	133 020	Manufactured[3]	1.6	212 832	1.6	212 832
Total crustacean feeds				275 176		275 176
Total aquafeeds				**7 108 374**		**2 588 078**

[1] Carp production data modified by subtracting 90 000 tonnes from FAO data for 2004 on the assumption that 90 000 tonnes are produced from stock-and-harvest fisheries that are not fed.
[2] About 10 000 tonnes of manufactured feeds are used in freshwater fish culture.
[3] Farm-made feeds are used in some prawn and penaeid shrimp farms in extensive farms in Kerala, Orissa and West Bengal. The exact volume of use is not known, but it is not likely to exceed 30 000 tonnes.

Source: FAO (2006) and as modified.

Many carp farmers in the Kolleru area feed their fish only with de-oiled rice bran and rice polish up to a size of 500 g, whereafter oil seed residues and other protein concentrates are added to the feed. The daily ration depends on fish body weight as shown in Table 14. More details on the composition of farm-made feeds and feeding practices may be found in Ayyappan and Ahamad Ali (2007).

The American Soybean Association (ASA) has been conducting trials in the Cauvery delta region of Tamil Nadu (Thanjavur district) to compare the performance of carps fed traditional farm-made feeds and an extruded floating feed. It is reported that the fish on extruded floating feeds reached market size (~450 g) earlier than fish on farm-made feeds and achieved a FCR close to 1:1, while the fish on farm-made feeds had a FCR of 2-3:1 (P.E. Vijay Anand, pers. comm.) The typical FCR of intensive carp culture systems using farm-made feeds ranges from 3 to 4:1. The cost of feed is typically Rs 13.5–15.75/kg of fish (US$0.3–0.35).

TABLE 13
Composition and estimated cost of farm-made feeds used in carp farms in the Kolleru area of Andhra Pradesh

Ingredient composition	Percent
De-oiled rice bran	80
Groundnut cake	10
Cottonseed cake	10
Proximate composition	
Crude protein	20
Crude fat	2
Crude fibre	15
Ash	17
Estimated cost (Indian Rs/kg)	4.5
Estimated cost (US$/kg)	0.1

Source: R. Ramakrishna, pers. comm. (2005).

TABLE 14
Daily ration for intensive carp farming systems in the Kolleru area of Andhra Pradesh

Fish size (kg)	Ration (% body weight/day)
<0.5	4.0
0.5–1.0	2.5–2.0
1.0–2.0	2.0–1.5
>2.0	1.5

5.2 Feed production for shrimp and prawns

India has a well-established capacity to produce feeds for shrimp and prawn culture. Until 1990 the sector relied solely on farm-made feeds. With the advent of large-scale semi-intensive shrimp culture in the early 1990s, vast quantities of shrimp feeds were imported from Taiwan Province of China and Thailand. However, imports have gradually been replaced by domestically produced feeds. Currently, the domestic shrimp feed manufacturing capacity exceeds demand. However, about 3 000 tonnes of shrimp feed is imported from Indonesia, China, Taiwan Province of China and South Africa to cater to the needs of niche markets. Additionally, about 30 tonnes of larval shrimp feeds are imported as India lacks the capacity to produce these specialty diets.

Many of the traditional, extensive shrimp and prawn farms in Kerala and West Bengal either provide no feed or only use farm-made feeds. Production from these systems is likely to be about 30 000 tonnes a year. However, the bulk (130 000–140 000 tonnes) of freshwater prawn and shrimp production is reliant on manufactured feeds. In 2004, an estimated 193 500 tonnes of prawn and shrimp feeds were manufactured and sold in India.

India has about 28 feed mills dedicated to the production of freshwater prawn and shrimp feeds (Table 15). Ten of these mills are subsidiaries to international aquafeed companies. Collectively, these companies account for 90 percent of shrimp and prawn feed sales in India.

Table 16 details the regional distribution of shrimp and prawn feed mills. It is apparent from this table that India has an excess shrimp and prawn feed manufacturing capacity. The installed capacity exceeds 500 000 tonnes per year, twice the current annual requirement. However, the shrimp feed business is highly seasonal (Figure 8). As a result, in the past disruptions in feed distribution have occurred periodically during the peak season (May–July). It is estimated that at the peak of shrimp production, the country requires about 1 100 tonnes of feed per day. The current installed capacity of 1 900 tonnes/day implies that supply disruptions are now less likely to occur. In spite of the adequate to excess capacity, many foreign feed manufacturers still consider India as a growing market in the shrimp feed business and are investigating the possibility of entering it directly or through a local partner.

TABLE 15
Companies involved in the production of freshwater prawn and marine shrimp feeds in India

Company	No. of plants	Description
CP India	2	Thailand-based multinational feed company
Avanti	1	Local company that has technology partnership with Thai Union, a leading feed company in Thailand
Waterbase	1	Local company that has technology partnership with INVE, a Belgian company specializing in *Artemia* and larval feeds
Higashimaru	1	Local company that bought technology and brand name licence from Higashimaru, Japan
Grobest	1	A multinational feed company based in Taiwan Province of China
Godrej Agrovet	1	The largest livestock feed company in India that has recently entered into a collaboration agreement with Uni-President of Taiwan Province of China, a multinational shrimp feed company
Gold Mohur	1	A subsidiary of Godrej Agrovet (previously owned by Hindustan Lever) that uses the brand licence of Hanaqua Feeds, Taiwan Province of China
Laila Global	1	Local company that has partnered with Global Feeds of Indonesia
Cargill Matrix	1	The largest livestock feed company in the world that has recently entered into a partnership arrangement with a local company
Local	18	Small-scale feed mills (average capacity 1 tonne/hour) that produce their own formulations or formulations provided by the farmers

Steam pelleting technology combined with post-pellet conditioning is used to manufacture prawn and shrimp feeds in India. Most feed mills have installed capacities for fine grinding, extended pre-conditioning (multipass, steam-jacketed conditioners with 1–2 minutes of retention time) (Figure 9), pelleting through die holes down to 1.8 mm and live-steam post-conditioning. Crumblers are used to produce particles for feeding PLs stocked in ponds.

Specifications used by manufacturers of prawn feeds are shown in Table 17. Nutrient density of freshwater prawn feeds is lower than that of marine shrimp feeds (Table 18). Indian shrimp farmers have high quality expectations. The feeds are expected to have at least three hours of water stability and low levels of fines. Farmers expect shrimp to grow to about 3 g in size after the first four weeks of stocking; thereafter they are expected to grow at a rate of 2 g/week until they reach about 25 g. After reaching 25 g, they are expected to grow at a rate of 3 g/week. In 2004, MPEDA released a set of quality specifications for shrimp feeds in India (Table 19). Compliance is voluntary at present. The specifications are considered incomplete because many key nutrients such as phosphorus and vitamin C have not been specified.

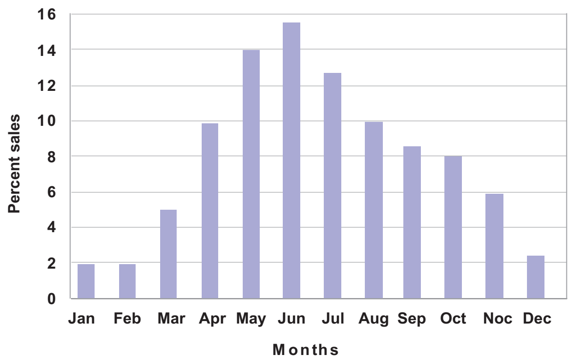
Farmers frequently topcoat the feeds with vitamins, minerals, squid oil, lecithin, *Spirulina*, probiotic bacteria and yeast, immuno-stimulants and feed attractants. Some farmers topcoat every feed they use. However, the majority only topcoat their feeds for use during specific production phases when they consider growth rates to be declining or when environmental conditions are unfavourable. Evaluation of the effectiveness of topcoating is lacking,

TABLE 16
Regional distribution of shrimp and prawn feed manufacturing plants in India

Region	Number of feed plants	Installed capacity** (tonnes/day)
Andhra Pradesh, northern*	10	740
Andhra Pradesh, southern	11	320
Tamil Nadu	6	720
Kerala	1	120
Total	**28**	**1 900**

* One feed plant located in the Union Territory of Pondichery has been included in the northern Andhra Pradesh .
** Estimate based on 20 work hours per day.

FIGURE 8
Monthly sales of shrimp feed in India



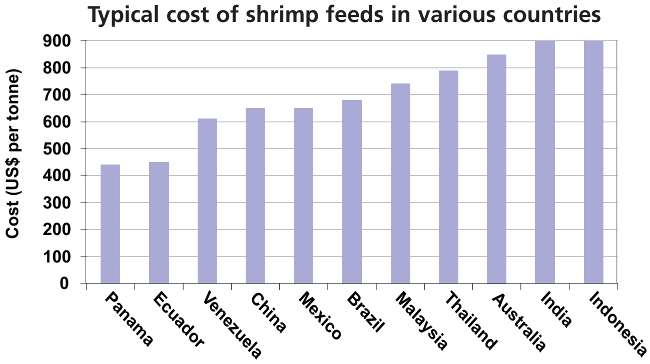
although some preliminary investigations reveal that most water-soluble vitamins and minerals are lost. It is estimated that top-coating typically increases the cost of feed by Rs 1 500 (US$33.33) per tonne.

The increase in global supply of farmed shrimp against a relatively stable demand in recent years has caused a gradual and possibly irreversible fall in the price of shrimp. As shrimp is a global commodity, producer countries need to be highly competitive. This competitiveness is even more important for countries such as India in which domestic consumption of shrimp is insignificant and which relies almost exclusively on exports. While India is competitive in terms of labour costs, it is highly uncompetitive with respect to feed and energy costs. Figure 10 shows that feed price is the highest among the major shrimp producing countries. This is in spite of the fact that India enjoys a competitive position with respect to the price of soybean meal and wheat in comparison with other major shrimp producers in Southeast Asia (Table 20). However, India is at a considerable disadvantage with respect to the price of fishmeal, all of which is imported, and for the tariffs imposed on imported additives. One should bear in mind, however, that *L. vannamei* is the predominant species in all major shrimp producing countries except Viet Nam, India and Bangladesh where *P. monodon* is still the dominant species. *L. vannamei* feeds are lower in nutrient density and quality when compared to *P. monodon* feeds and therefore cheaper.

FIGURE 9
Shrimp pellet mill with triple-pass conditioning

Steam pelleting technology combined with post-pellet conditioning is used to manufacture prawn and shrimp feed in India

FIGURE 10
Typical cost of shrimp feeds in various countries



Source: data collected by the author in 2004.

TABLE 17
Specifications commonly used for freshwater prawn feeds manufactured in India

Feed class	Target prawn size (g)	Feed type	Feed size (mm)	Crude protein (%)	Crude lipid (%)	Price/tonne*	
						Indian Rs	US$
Starter	0.5–5	Crumble	1.0–1.5	32–40	4–8	36 000–48 000	800–1 067
Grower	5–25	Pellet	2.0–2.3	24–30	3–4	24 000–36 000	533–800
Finisher	>25	Pellet	2.3	18–28	3–4	20 000–28 000	444–622

* Price range reflects protein content.

TABLE 18
Specifications commonly used for marine shrimp feeds manufactured in india

Feed class	Target prawn size (g)	Feed type	Feed size (mm)	Crude protein (%)	Crude lipid (%)	Price/tonne*	
						Indian Rs	US$
Starter	0.5–5	Crumble, short-cut pellets	0.5–1.8	40–44	6–8	44 000–48 000	978–1 067
Grower	5–20	Pellet	1.8–2.3	38–42	4–8	41 000–43 000	911–956
Finisher	>20	Pellet	2.3	36–38	4–8	38 000–41 000	844–911

* Range in price reflects range in protein level.

TABLE 19
Quality norms prescribed by the Marine Products Export Development Authority for shrimp feeds sold in India (percent dry matter basis except otherwise indicated)

	Starter	Grower	Finisher
Crude protein	**40–45**	**30–35**	**30–35**
Non-protein nitrogen	**<0.2**	**<0.2**	**<0.2**
Crude lipid	**6–8**	**6–8**	**6–8**
Crude fibre	**3–4**	**3–5**	**3–5**
Digestible energy (kcal/kg of feed)	**3 200–3 600**	**3 200–3 600**	**3 200–3 600**
Essential fatty acid			
Linoleic acid + Linolenic acid	**0.5**	**0.5**	**0.5**
Eicosapentenoic acid (EPA) + Decosahexaenoic acid (DHA)	0.5	0.5	0.5
Phospholipids (lecithin)	**1.0**	**0.4**	**0.4**
Cholesterol	**0.5**	**0.2**	**0.2**
Astaxanthin (ppm)	**–**	**–**	**200**
Essential amino acid			
Arginine	2.03–2.32	1.74–2.03	1.74–2.03
Isoleucine	1.23–1.40	1.05–1.23	1.05–1.23
Methionine	0.84–0.96	0.72–0.84	0.72–0.84
Phenylalanine + tyrosine	1.89–2.16	1.62–1.89	1.62–1.89
Phenylalanine	1.40–1.60	1.20–1.40	1.20–1.40
Tryptophan	0.28–0.32	0.24–0.28	0.24–0.28
Histidine	0.74–0.84	0.63–0.74	0.63–0.74
Lysine	1.86–2.12	1.59–1.86	1.59–1.86
Threonine	1.26–1.44	1.08–1.26	1.08–1.26
Valine	1.40–1.60	1.20–1.40	1.20–1.40

TABLE 20
Cost of feed ingredients (US$/tonne) in various Asian countries

Country	India	Thailand	Viet Nam	Malaysia	Indonesia	Philippines
Soybean meal (Hi-Pro)	297	348	348	324	300	357
Fishmeal (imported, S. American, prime)	733	740	736	661	675	622
Fishmeal (local)	467	666	536	500	545	505
Wheat flour	233	331	324	346	342	342
Import tariff on additives (%)	31.62	10.0	10.0	0	15.0	3.0

Source: data collected by author in 2004.

One of the highly significant factors influencing the price of shrimp feed in almost all of Asia is the cost of distribution. Unlike in Latin America, shrimp farming is largely in the hands of small- and medium-size producers. Farms that have 5–10 ponds each of 0.8–1.0 ha are typical of semi-intensive shrimp farms in India, whereas a typical South American farm is ten times larger in size. To cater to the small and medium farmers who are distributed widely and have no access to bank credit, feed companies in Asia rely on a distribution network. The feed distributors buy feed from the feed company on secured credit and store and sell it to the farmers on unsecured credit. Since the distributor is local, they have the ability to monitor the farmers' activities and know when and how to collect their dues. For this service, the feed company pays the distributor a commission of 12–15 percent on the retail price.

6. PROBLEMS AND CONSTRAINTS IN THE USE OF COMMERCIALLY MANUFACTURED FEEDS FOR SMALL- AND MEDIUM-SCALE AQUACULTURE

As discussed above, commercially manufactured feeds are widely used in freshwater prawn and marine shrimp farming in India. Farm-made feeds are used only in the traditional, extensive farming systems in Kerala and West Bengal. These systems are stocked at extremely low densities as the size and nature of the ponds (large, flood- or tidal-fed ponds) do not facilitate control of management protocols. Unless these systems are converted into manageable units, it is simply not viable to use commercial feeds.

For the small- and medium-scale farmers, who comprise the majority of the prawn and shrimp farmers in India, the major constraint in the use of commercially manufactured feed is the cost of production. The relatively constant feed price compared with falling shrimp prices means that feed cost as a proportion of total production cost continues rising to unprofitable levels. It is possible to reduce feed costs by by-passing the distribution network and buying directly from the feed manufacturer on a cash basis. For the small- and medium-scale farmers, such a bypass is not a realistic option as they lack the economy of scale and access to adequate credit. In such a situation, one of the following may occur:

1. The shrimp production and processing sector will start to integrate vertically to achieve higher efficiencies. A number of shrimp feed manufacturers in India already own hatcheries, farms and processing factories. A number of large shrimp producers already own or consider owning a feed manufacturing business. In this scenario, small- and medium-scale farmers will either sell their operations to the larger players or become contract producers.
2. Small- and medium-scale farmers will achieve better economies of scale through a cooperative form of collective bargaining and/or higher efficiency of feed use so that the proportion of feed cost to total feed cost is held in check.
3. The feed manufacturers will reduce their profit margins or improve their production and distribution efficiencies to pass on the margin differential to the farmers.

Scenarios (1) and (3) will depend on market forces, while scenario (2) will depend on deliberate policy intervention by government and other institutions (see recommendations).

Contrary to the prawn and shrimp farming sectors, fish farmers still rely mainly on farm-made feeds. The primary reason why manufactured feeds are not used in fish farming in India is the farmers' reluctance to use them based of the perception that they would not be cost-effective. This reluctance has in turn retarded the interest of feed manufacturers to develop and launch feeds for the fish farming sector. Preliminary information emerging from trials carried out by some of the large feed manufacturers and others (e.g. Godrej Agrovet and ASA) in India show that the perception of the farmers may not be correct. Under intensive farming conditions using current farm-made feeds at a cost of Rs 4–4.5/kg (US$0.08–0.10) the average FCRs range from 3 to 4:1. The cost of feed to produce one kg of fish is around Rs 14.00–15.75 (US$0.31–0.35). This means that an extruded feed with a FCR of 1:1 at a cost of Rs 13–14/kg (US$0.28–0.31) should theoretically be acceptable to the farmers. The recent drop in the price of extrusion plants made in China makes the prospect of affordable extruded feeds a real possibility. It is predicted that at least 30 percent of intensive carp, catfish and snakehead farmers are likely to use extruded feeds before 2010. This would equate to a production of about 250 000 tonnes of feeds, resulting in a doubling of the current level of aquafeed production.

The use of manufactured feeds would also lead to a reduction in water and pond substratum pollution, thereby reducing the costs associated with managing water quality and stress/disease, and this would facilitate higher stocking densities and yields. In addition, labour costs could be substantially reduced.

However, there are two major constraints to the use and manufacture of compounded feeds for fish farming in India. First, farmers are constrained by the low price of fish in certain markets and during certain times of the year such that they cannot afford manufactured feeds. Second, feed manufacturers are equally constrained by the buying power of the farmers, which reduces their flexibility with respect to the use of ingredients to produce cost-effective feeds. Remedial suggestions are provided in section 7.

7. RECOMMENDATIONS FOR IMPROVED UTILIZATION OF INDUSTRIALLY MANUFACTURED AQUAFEEDS

It is clear from the above synthesis that industrially manufactured feeds confer several microeconomic benefits. The lower FCRs achieved by the use of manufactured feeds leads to the improved utilization of national feed ingredient resources. Moreover, farming operations are simplified and streamlined leading to improved operational efficiency, higher yields per unit volume/area of water and higher profitability. Other benefits include improved fish quality, farm biosecurity and sanitation, etc. To improve the utilization of industrially manufactured feed, the following recommendations are made.

7.1 Freshwater fish culture sector

The primary and immediate need is to help farmers to understand the value of manufactured feeds. There have been some "on-farm" trials to demonstrate the performance of industrially manufactured extruted pellets in intensive culture of carps (see sections 5.1 and 6 for results of some of the trials conducted). Although some of these trials use a relatively expensive feed formulation, it is anticipated that a less expensive formulation could result in an equivalent economic performance. Trials with alternative, lower cost formulations will provide useful information for farmers and feed manufacturers alike. Research institutions working on freshwater fish nutrition need to place greater emphasis on understanding the nutrient composition of local, commercially available ingredients, such as de-oiled rice bran, rice polish, wheat bran, maize, sorghum, millets, broken rice, groundnut cake, cotton oilseed cake, soybean meal, sunflower meal, copra meal, maize gluten meal, local fishmeal, shrimp meal, blood meal, meat meal and feather meal. This would require closer collaboration between research institutions and the industry.

The long-term goal for improved utilization of feeds in freshwater fish farming is to improve the market price for fish. This goal is only possible through a systematic and sustained campaign to promote fish as food and ensuring that fish of a high quality are available to the consumer. The success of such an initiative requires all stakeholders (feed manufacturers, farmers, suppliers of other inputs to the farmers, and those in fish supply business) to unite and pool their resources. Broiler and egg producers in India have been successful in running and benefiting from such generic campaigns. Lessons can also be learned from generic promotion campaigns for soybeans, milk, cotton and catfish.

7.2 For the freshwater prawn and marine shrimp culture sector

The primary and immediate objective is to address those factors that have an impact on the price of feed. Among others these include:

1. The import tariff on additives is excessively high in comparison with other major shrimp producers in Asia and needs to be reduced.
2. The import permitting system for feed ingredients needs to be standardized and harmonized such that the importation process is free from unnecessary bureaucratic control.
3. It is possible that some of the available formulated feeds are overformulated for certain nutrients and ingredients. Facilities need to be established to conduct field trials. Creative solutions, such as the establishment of pubic / private entities, need to be found.
4. The nutritive value of locally available ingredients such as soybean meal, fishmeal, fish oil and shrimp meal may be improved by improving the processes used to produce these commodities. Policy-level initiatives such as technological assistance and incentives for processors would help.
5. The nutritive value of locally available ingredients such as coarse grains, grain by-products and oilseed residues for freshwater prawn and marine shrimp need to be established through research.

6. While scientists in research institutions such as the Central Institute of Brackish-water Aquaculture and the Central Institute of Freshwater Aquaculture have developed low-cost feed formulation options for shrimp and freshwater prawns, respectively, reliable feed performance data under field conditions prevent widespread use of such formulations. Closer collaboration between public institutions and the industry is required to achieve this goal.
7. Feed application research is necessary to improve the efficiency of feed utilization to reduce the cost of feed per unit of production. A study by Hari *et al*. (2004) is a case in point. They found that *P. monodon* raised on 25 percent protein feeds grew as fast as, or slightly better than, those raised on 40 percent protein feeds as long as the culture systems are provided with a source of carbohydrate (tapioca flour) to promote heterotrophic bacterial growth. A 35 percent reduction in feed cost and a 54 percent increase in revenue were recorded for the low protein feed plus carbohydrate treatment when compared to the high protein feeds alone.
8. A significant handicap for the small- and medium-scale farmers in managing the cost of feed is their lack of economies of scale and cheaper credit. Efforts should be made by the central and state government agencies promoting aquaculture to nurture the development of farmer cooperatives that would provide collective bargaining power for the purchasing of feeds, credit and other inputs.
9. Disease problems such as loose shell disease severely affect feed utilization. More resources should be employed on a timely basis to address such problems so that farmers can be educated on ways to prevent such outbreaks.

The long-term aim should include working towards and improvement in the market price for shrimp. While new export markets and opportunities need to be identified and opened, the biggest opportunity most likely remains at home. As the Indian economy improves and disposable income of the growing middle class increases, efforts to increase domestic consumption of shrimp and freshwater prawns are likely to be effective in increasing local demand. The generic campaign ideas discussed above for freshwater fish are also applicable to the shrimp and freshwater prawn sectors.

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APPENDIX
Quality norms and standards of livestock feeds in India

A.1. Quality norms (% maximum) prescribed by CLFMA for dairy feeds

Characteristic	Dairy special feed	Type I feed	Type II feed	Type III feed
Moisture	12.0	12.0	12.0	12.0
Crude protein (dry matter basis)	22.0	20.0	18.0	16.0
Undegraded protein	8.0	-	-	-
Crude lipid	3.0	2.5	2.5	2.0
Crude fibre	7.0	7.0	12.0	14.0
Acid-insoluble ash	3.5	4.0	4.5	5.0

A.2. Quality norms (% maximum except otherwise indicated) prescribed by CLFMA for poultry feeds

Characteristic	Chick feed	Grower feed	Layer feed I	Layer feed II	Broiler starter feed	Broiler finisher feed	Breeder chick feed	Breeder grower feed	Broiler breeder feed	Layer breeder feed	Broiler male breeder feed
Moisture	12	12	12	12	12	12	12	12	12	12	12
Crude protein	18	14	16	14	20	18	18	14	16	16	14
Crude lipid	2	2	2	2	3	3	3	3	3	3	3
Crude fibre	7	8	8	10	6	5	5	7	7	7	7
Acid-insoluble ash	4	4	4	4	4	4	4	4	4	4	4
Metabolizable energy *(minimum cal/kg)*	2 600	2 300	2 500	2 300	2 600	2 700	2 600	2 400	2 500	2 500	2 400

A.3. Quality standards (% maximum) set by the Bureau of Indian Standards for poultry feeds

Characteristic	Broiler starter feed	Broiler finisher feed	Chick feed	Growing chicken feed	Laying chicken feed	Breeder layer feed
Moisture	11	11	11	11	11	11
Crude protein (N x 6.25)	23	20	20	16	18	18
Crude fibre	6	6	7	8	8	8
Acid-insoluble ash	3.0	3.0	4.0	4.0	4.0	4.0
Salt (as NaCl)	0.6	0.6	0.6	0.6	0.6	0.6

A.4. Quality standards set by the Bureau of Indian Standards for vitamins, minerals, amino acids and fatty acids in poultry feeds

Characteristic	Broiler starter feed	Broiler finisher feed	Chick feed	Growing chicken feed	Laying chicken feed	Breeder layer feed
Manganese *(mg/kg)*	90	90	90	50	55	90
Iodine *(mg/kg)*	1	1	1	1	1	1
Iron *(mg/kg)*	120	120	120	90	75	90
Zinc *(mg/kg)*	60	60	60	50	75	100
Copper *(mg/kg)*	12	12	12	9	9	12
Vitamin A *(IU/kg)*	6 000	6 000	6 000	6 000	8 000	8 000
Vitamin D_3 *(IU/kg)*	600	600	600	600	1 200	1 200
Thiamine *(mg/kg)*	5	5	5	3	3	3
Riboflavin *(mg/kg)*	6	6	6	5	5	8
Pantothenic acid *(mg/kg)*	15	15	15	15	15	15
Nicotinic acid *(mg/kg)*	40	40	40	15	15	15
Biotin *(mg/kg)*	0.2	0.2	0.02	0.15	0.15	0.20
Vitamin B_{12} *(mg/kg)*	0.015	0.015	0.015	0.01	0.010	0.01
Folic acid *(mg/kg)*	1.0	1.0	1.0	0.5	0.5	0.5
Choline *(mg/kg)*	1 400	1 000	1 300	900	800	800
Vitamin E *(mg/kg)*	15	15	15	10	10	15
Vitamin K *(mg/kg)*	1.0	1.0	1.0	1.0	1.0	1.0
Pyridoxine *(mg/kg)*	5	5	5	5	5	8
Linoleic acid *(mg/kg)*	1	1	1	1	1	1
Methionine + cystine *(g/100 g)*	0.9	0.7	0.6	0.5	0.55	0.55

Analysis of feeds and fertilizers for sustainable aquaculture development in Indonesia

Abidin Nur
Centre for Brackishwater Aquaculture Development
Jepara, Central Java
Indonesia

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SUMMARY

Aquaculture production in Indonesia makes a significant contribution to export earnings, domestic food supply and conservation. Aquaculture production in 2003 was 1.22 million tonnes valued at US$1.72 billion and in 2004 had increased to 1.47 million tonnes valued at US$2.16 billion. In 2003 around 60 percent of total aquaculture production was from finfish culture, followed by seaweed (18.9 percent), crustaceans (16.2 percent), molluscs (0.3 percent) and others (4.7 percent). In terms of value, shrimp are the most important and during 2003 shrimp export earnings amounted to US$1.1 billion, which comprised almost 50 percent of total fisheries exports. Pacific white shrimp, *Litopenaeus vannamei* is now the most important shrimp aquaculture species in Indonesia.

Culture systems range from extensive pond culture to intensive culture of shrimp and fish in paddy fields, earthen and concrete ponds, raceways and cages. Extensive fish aquaculture is reliant on fertilization with organic and inorganic fertilizers and the use of supplementary feeds. The use of farm-made feeds in Indonesia is limited, though small-scale farmers are encouraged to use it and in particular to make better use of local ingredients. Because of transport and labour costs organic manures are more expensive to use than inorganic fertilizers. Semi-intensive milkfish culture is also dependent on organic manure for the production of natural foods. Organic fertilizer is also used in semi-intensive shrimp culture though inorganic fertilizers are now preferred to reduce the chances of disease transmission. Urea and triple super phosphate are the most widely used inorganic fertilizers in brackish-water aquaculture. In 2003, some 19 600 tonnes of organic and 7 600 tonnes of inorganic fertilizer were used in brackish-water and freshwater pond aquaculture.

Shrimp are fed on formulated, industrially manufactured pellets, as are tilapia and other freshwater fish species under semi-intensive and intensive culture conditions. Farm-made feeds are used mainly for low value species and consist mainly of trash fish, sun-dried fish or locally produced fishmeal as the primary protein source that is mixed with rice bran, corn meal, molasses, tapioca and other seasonally available ingredients. The availability of trash fish is decreasing and this is a major constraint facing the small-scale aquaculture sector, as well as intensive cage and pond culture of grouper. A moist pellet for grouper aquaculture has recently been developed. Seven million tonnes of animal feed was produced in 2005, of which 595 000 tonnes consisted of aquafeeds. Indonesia is highly dependent on imported fishmeal and fish oil and this, as well as the competition from the poultry sector is considered as a future constraint for the aquafeed industry. The bulk of the soybean meal, squid meal and wheat gluten used in aquafeeds is also imported. Local fishmeal processing technology must be improved to reduce the country's dependence on imports and further research is required to make better use of alternative, locally available, ingredients in aquafeeds.

Indonesia uses a relatively small proportion of the area that is available and or suitable for aquaculture and this together with the intensification of culture practices provides opportunity for rapid growth of the sector. Aquaculture is expected to grow at over 17 percent per annum and it is projected that aquaculture production will increase to over 4 million tonnes by 2009 and it is expected that there will be a higher dependency on commercial aquafeeds. To meet the demand the aquafeed industry needs to gear it appropriately and find alternatives to minimize the fishmeal content in aquafeeds. The high feed demand of *L.vannamei* needs urgent attention. A more cost effective feed needs to be developed to improve efficiency and to reduce environmental impacts. Greater consumer awareness of food safety issues requires the feed industry to pay greater attention to traceability of feed materials and feed processing technology.

1. GENERAL OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

1.1 Introduction

Aquaculture has a long history in Indonesia and began with the brackish-water pond culture of milkfish (*Chanos chanos*) on the island of Java. Subsequently, wild caught shrimp larvae were introduced into the ponds and grown extensively either in monoculture or polyculture with milkfish (Poernomo, 2004). The animals were not fed and relied entirely on natural food (algae, plankton and diverse benthic organisms) which grow prolifically in warm, shallow, brackish-water ponds. Initial production levels were low (200–250 kg/ha/crop), but under favourable conditions two crops could be harvested per year (Goddard, 1996). Extensive shrimp culture was initiated in eastern Indonesia (South Sulawesi) in the mid 1960s and from there spread to other islands with suitable environments. The first shrimp hatchery in Indonesia was commissioned in the early 1970s in Makassar (South Sulawesi) followed by another in Jepara (Central Java) (Poernomo, 2004).

During the last decade the area under culture has increased significantly (Table 1) and farming practices have been intensified and this has led to substantial increases in production. The expansion was driven largely by export and local consumer demand, consumer awareness and the ability to grow aquatic organisms year round. Moreover, capture fisheries have declined and this gave further impetus for the growth of the aquaculture sector.

The government revitalization programme promotes the culture of tuna, shrimp and seaweed, primarily for export. Other species are cultured mainly for domestic consumption as well as for conservation purposes. Approximately 2.4 million people are employed in the aquaculture sector (Ditjenkan Budidaya, 2005).

Aquaculture practices in Indonesia range from extensive to intensive farming of fish and shrimp. Black tiger shrimp, *Penaeus monodon* and in particular Pacific white shrimp, *Litopenaeus vannamei* are the two most important species grown for the export market. *L. vannamei* has been farmed in East Java since 2001 and from there has distributed throughout the country (Taw, 2005a). Shrimp aquaculture production has increased significantly within the last few years. Awareness of best management practices (proper pond design and construction, stocking of high quality seed, water quality management, and good feed and best feed management practices) and market forces have contributed to shrimp aquaculture development in Indonesia.

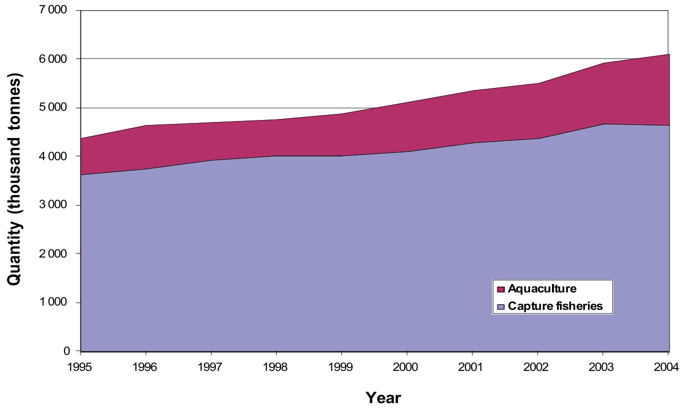
Giant freshwater prawn, *Macrobrachium rosenbergii*, is a high value species and is currently produced primarily for domestic consumption. The species has been domesticated and a new variety caleed “GI-Macro” (Genetic Improvement of *Macrobrachium*) is now used to produce high quality broodstock and seed. Several freshwater fish such as common carp, tilapia, giant gouramy, snakeskin gouramy, kissing

TABLE 1
Area under aquaculture in Indonesia during 2000–2003

Aquaculture area (ha)	2000	2001	2002	2003	Average increase per year (%)
Mariculture [1, 2]	601	699	932	961	19.97
Brackish-water pond	325 530	351 655	360 239	370 824	4.63
Freshwater pond	77 647	85 900	94 240	97 821	8.66
Cage[3]	76	80	86	93	7.46
Floating net cage [2,3]	183	354	356	373	34.60
Rice field	157 346	150 680	148 909	151 414	-1.26
Total (ha)	**561 383**	**589 368**	**604 762**	**621 486**	

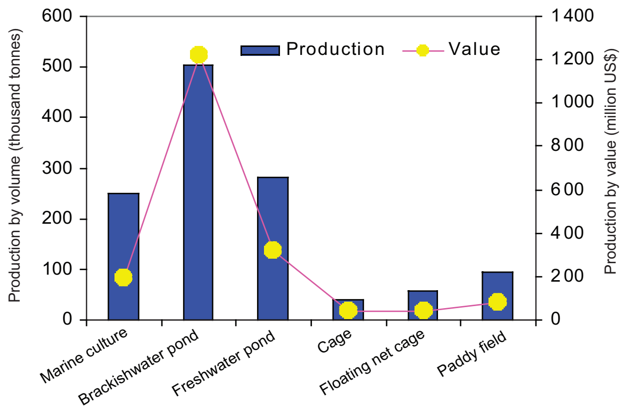
[1] Mariculture include only marine cage culture and excludes area used for seaweed culture;
[2] Data converted into hectare from the information available on the number of units of marine fish cage and floating net cage;
[3] Cage and floating net cage include only freshwater cage culture
Source: Ditjenkan Budidaya (2005)

FIGURE 1
Capture fisheries and aquaculture production in Indonesia during 1995–2004



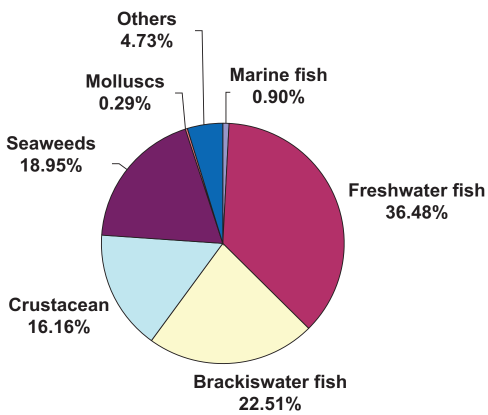
Source: FAO (2006)

FIGURE 2
Aquaculture production by volume and value in different culture environment in Indonesia, 2003



Source: Ditjenkan Budidaya (2004)

FIGURE 3
Aquaculture production in Indonesia by major species groups in 2003



Source: Ditjenkan Budidaya (2004)

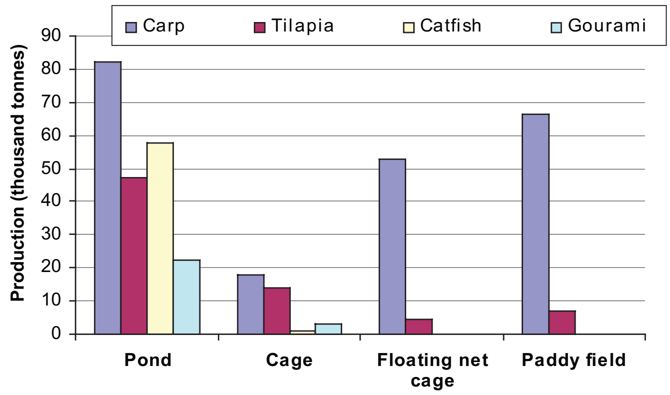
gouramy, catfish, snake head, java barb, river eel, sand gobies, and hows carp are also farmed and production of these species has increased yearly. Fish are farmed for export as well as for domestic consumption. Brackish-water fish aquaculture is dominated by milkfish, which is now also grown in offshore marine cages. Other brackish-water fish species include mullet, seabass and tilapia. Mud crab is also produced in brackish-water systems. Seaweed, grouper, lobsters, colour shells and pearls are produced in the marine environment. Seaweed culture has recently been revitalized due to the rapid growth rates, low capital investment and simple culture technologies.

1.2 Production

In 2004 Indonesia was estimated to have produced about 6.12 million tonnes of aquatic products from capture fisheries and aquaculture (FAO, 2006). Capture fisheries contributed about 76.0 percent of total production while the remaining 24.0 percent was from aquaculture. Over the last ten years aquaculture production has almost doubled increasing from 0.74 million tonnes in 1995 to 1.47 million tonnes in 2004 (Figure 1). Aquaculture production in 2003 was 1.22 million tonnes valued at US$1.72 billion and in 2004 had increased to 1.47 million tonnes valued at US$2.16 billion (FAO, 2006). Aquaculture production by volume and value in different culture environment in 2003 are shown in Figure 2. Mariculture, brackish-water pond, freshwater pond, cage culture, floating net cages and paddy field culture accounted for 20.0, 41.0, 22.9, 3.3, 4.7 and 7.7 percent respectively of the total aquaculture production. The contribution of the different species groups in aquaculture is shown in Figure 3.

Marine aquaculture is dominated by grouper and seaweeds, which accounted for 0.7 percent and

FIGURE 4
Aquaculture production of the four major freshwater fish species in different aquaculture systems in 2003



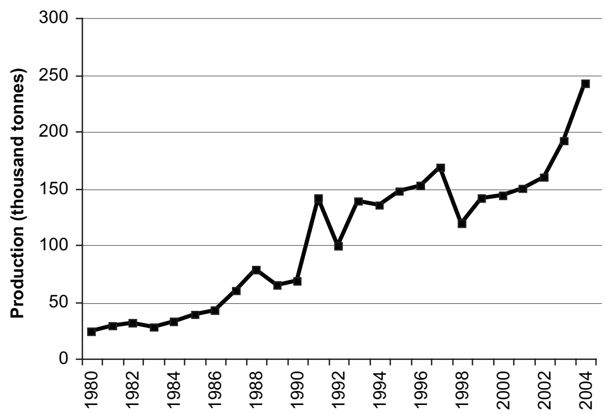
Source: Ditjenkan Budidaya (2004)

18.9 percent, respectively, of the total aquaculture production. Milkfish (18.6 percent) and shrimp (15.7 percent) are the main species produced in brackish-water ponds while carp, tilapia, catfish, and gouramy are the major species produced in different freshwater aquaculture systems (Figure 4).

In terms of value, shrimp dominate aquaculture exports. In 2004, approximately 143 550 tonnes of shrimp (headless), valued of US$1.1 billion were exported, which accounted for about 50 percent of the total fisheries export (Ditjenkan Budidaya, 2005).

In terms of area (Table 1), marine aquaculture (19.97 percent/year) and floating net cage culture (34.6 percent/year) have grown substantially faster than other systems. This is mainly because of the increasing interest in grouper, seaweed, common carp, tilapia, catfish and gouramy aquaculture. The area under brackish-water ponds has decreased by 4.6 percent/year, particularly in South Sulawesi, East Java, West Java, Aceh, Lampung, East Kalimantan, North Sumatera and West Nusa Tenggara. However, the introduction of *L. vannamei* in 2001 (Briggs *et al*., 2004) ensured that shrimp production did not decline as well. The introduction of *L. vannamei* has, in fact, made a significant impact on shrimp production in Indonesia (Table 2; Figure 5). This species was initially cultured in East Java and the first successful pond yields were 7–10 tonnes/ha, with animals reaching 15 g in 90 days at survival rates of 75–90 percent and FCRs of 1.1–1.4:1. However, major losses were recorded in 2002 as a result of white spot syndrome virus (WSSV). At present with a better understanding of the species and the production of specific pathogen free (SPF) post larvae (PLs), *L. vannamei* is once again widely farmed in Indonesia (Kopot and Taw, 2004)

FIGURE 5
Indonesian shrimp aquaculture production during 1980–2004



Source: Ditjenkan Budidaya (2004)

L. vannamei has several advantages over *P. monodon*, such as faster growth, a wider salinity tolerance, tolerance to higher densities and a lower protein demand (Briggs *et al*., 2004). High density culture of *L. vannamei* is commonly practised, but lower stocking

TABLE 2
Shrimp aquaculture production (tonnes) in Indonesia during 2000–2004

Shrimp	2000	2001	2002	2003	2004
P. monodon	94 000	104 000	113 000	90 000	80 000
L. vannamei	0	2 000	7 000	43 000	80 000
Others*	50 000	43 000	44 000	45 000	45 000
Total	**144 000**	**149 000**	**164 000**	**178 000**	**205 000**

* Others include lobster, local white shrimp, Metapenaeus shrimp, and mysid
Source: Akiyama (2004)

FIGURE 6
High density (200 PL/m²) culture of Pacific white shrimp (*Litopenaeus vannamei*) in concrete ponds

densities of 20 animals/m² have recently been reported from East Java. Production after 2–3 months ranges from 800–2 000 kg/ha (CP Shrimp News, 2004, 2005).

The sharp increase in shrimp production over the last few years (Figure 5) is mainly due to higher stocking rates as well as the higher production capacity of *L. vannamei*. In intensive culture, *L. vannamei* are commonly stocked at over 100 PLs/m² and production normally ranges from 10.0–15.0 tonnes/ha/year (Taw, 2005a).

For example, a farm in Banyuwangi-East Java (Figure 6) using 0.4 ha of concrete ponds (stocked at 200 PLs/m²) produces 8 tonnes of shrimp (80 shrimps/kg) after 100 days (Nur, Arifin and Latief, 2004). Shrimp farming practices vary somewhat from region to region depending on the local conditions and financial conditions. Shrimp production also varies according to the culture technology applied (Table 3). In general, however, the introduction of SPF *L. vannamei* to Indonesia has prompted a move towards low water exchange, greater bio-security and the use of concrete or polyethylene lined ponds for high density culture (Taw, 2005b).

In 2004, a total of 5.3 billion PLs (or 65 percent of production capacity) were produced from about 13 hatchery enterprises (Ditjenkan Budidaya, 2005). Efforts to domesticate the broodstock of *P. monodon*, *P. stilyrostris* and *L.vannamei* have been initiated at Centre for Brackishwater Aquaculture Development (CBAD), Jepara since 2003 to support and provide high quality broodstock for hatcheries in Indonesia.

The higher pond production capacity of *L.vannamei* has resulted in higher feed inputs into the systems. Excretory products and uneaten feed have potential to accumulate in the sediment and ultimately may have an adverse affect on internal pond and or surrounding waters. Fortunately the dietary protein requirement of *L.vannamei* is lower than that of *P. monodon* (Tacon, 2002; Briggs *et al.*, 2004; Cuzon *et al.*, 2004; Akiyama, 2004). The protein content of *L.vannamei* feeds range from 28–42 percent. Field experience has shown that growth is impaired under

TABLE 3
Characteristics of various shrimp culture technologies in Indonesia

System and species	Stocking density (PL/m²)	Yield (tonnes/ha)	Average size (g)
Monoculture of *L. vannamei*			
Normal stocking density	60–80	8–10	16–20
High stocking density	130–150	14–30	14–18
Monoculture (partial harvest)	130–150	23–25	12–20
Bacterial floc (zero water exchange)	130–150 280	20–24 49.7	16–20
Polyculture with *P. monodon*			
P. monodon	40–50	7.5	
L.vannamei	20–30	3.5	-

Source: Taw (2005b)

high stocking densities (200 PL/m^2) at a protein content of less than 35 percent (Widyatmoko, pers. comm., 2005). While current on-farm stocking densities are 50–125 PL/m^2 the 35 percent protein diet is still the most widely used feed and this is affecting pond ecosystems and the environment. It is, therefore, important that further research be undertaken on the economics and nutrient budget of *L.vannamei* aquaculture to evaluate its sustainability in the future.

2. REVIEW AND ANALYSIS OF AQUACULTURE FEED AND FEEDING

2.1 Fertilizer, feed ingredients and aquafeeds

The bulk of fish and shrimp production occurs in extensive and semi-intensive farming systems. In extensive pond culture, production is based on the use of organic and inorganic fertilizer to promote the growth of simple plants which form the base of the pond food chain (Goddard, 1996). In semi-intensive or intensive farming systems, fertilizer is used to stimulate phytoplankton growth as a water conditioner and to create a favourable environment for optimal growth and survival of fish and shrimp.

In Indonesia, the most commonly used inorganic fertilizers are urea and triple super phosphate (TSP). Other fertilizers used in aquaculture are super phosphate (SP36) (36 percent P_2O_5 and 5 percent Sulphur) and NPKS[1] (15:15:15:10). The types of fertilizers used and their application rates vary widely. Commonly used organic fertilizers are poultry and cattle manure. In 2003, some 19 600 tonnes of organic and 7 600 tonnes of inorganic fertilizer were used in brackish-water and freshwater pond aquaculture.

Organic fertilizer is often more expensive than inorganic fertilizers because of higher labour and transport costs. The current price of urea and TSP is US$0.13/kg and US$0.15/kg, respectively compared to chicken or cow manure at US$21.97/tonne (Sulistyo, pers. comm., 2005). Because of increasing concerns on bio-security on shrimp farms, the use of organic fertilizer is being restricted to protect the shrimp from potential disease transmissions. However, organic manure is preferred for freshwater pond and paddy field aquaculture. Milkfish production in brackish-water ponds is also largely dependent on organic fertilizers.

2.1.1 Feed ingredients and feeds

Feed ingredients for aquaculture are sourced locally and from abroad. Ingredient choice depends on nutrient content, digestibility and bioavailability, the cost of destroying anti-nutritional factors and toxic substances, availability and cost. Animal and plant materials are the most common feed ingredients, though some wastes and by-products of the food industry are also used.

Currently, around 70–80 percent of feedstuffs for shrimp and fish feeds are imported (Yanuartin, 2004; Sukria, 2004). Production of aquafeeds, particularly for carnivorous finfish species and marine shrimp, has so far been dependent upon the use of fishmeal and fish oil as cost-efficient sources of dietary protein and fat (Coutteau *et al.*, 2002). Fishmeal typically constitutes between 25 and 40 percent of formulated feeds for carnivorous fish and shrimp (Lee and Kim, 2001). Locally available feed ingredients are less used for shrimp diets due to inferior quality, competition for human consumption and inconsistent supplies. For instance, imported fishmeal (crude protein >65 percent is preferred over local fishmeal with protein content ranging from 33–55 percent. Moreover, the ash and lipid content of the local fishmeal were higher than the standards recommended for shrimp (Yanuartin, 2004).

In accordance with the projected growth of the aquaculture industry, and an increased demand for and possibly shortage of marine raw materials in the coming decade, there is a need to identify alternative protein sources for aquafeeds (Lee and Kim, 2001;

[1] Nitrogen, phosphorus, potassium and sulphur

Coutteau *et al*., 2002). Research on alternatives in Indonesia is on-going and in the recent past has focused on lupin meal (Sudaryono *et al*., 1999), corn meal (Nur, Latief and Kuntiyo, 2000), golden snail (Utomo, Suryana and Jusadi, 2003), shrimp head meal (Anon., 2004; Laining *et al*., 2004), fish and blood silage (Jusadi, Probosasongko and Mokoginta, 2004; Laining *et al*., 2004), soybean meal cake (Suprayudi, Mokoginta and Naim, 2004), golden snail (Utomo, Suryana and Jusadi, 2003) and *Spirulina platensis* (Panji and Suharyanto, 2003). The potential of alternative ingredients is determined by their proximate composition, availability and cost.

2.1.2 Feeding practices

By far the most common feeding practice in extensive and some semi-intensive aquaculture operations involves the use of organic and inorganic fertilizers and the provision of supplementary feeds. Supplementary feeds can include live or fresh natural food items, kitchen waste, and single processed feedstuff, farm-made feeds to factory manufactured pelleted aquafeeds (Tacon and De Silva, 1997). Semi-intensive and intensive culture systems in particular, are entirely dependent on commercial feeds.

The inappropriate use of feeds may have adverse effects both on the environment and the animals being farmed. Funge-Smith and Briggs (1998) reported that a high proportion of nutrients in waterways adjacent to intensive shrimp farms originate from commercial feeds due to low nitrogen retention by shrimp (see Table 4). However, information on the environmental impact of shrimp farming in Indonesia is limited. The low nitrogen retention by shrimp is caused by several factors such as, suboptimal feed formulation or quality of feed ingredients, overfeeding and poor water stability of feeds. Hence, there is considerable scope to reduce nutrient discharge from shrimp farming, by better feed management and improved feed formulation (Burford and Williams, 2001). Feeding rates should be related to the estimated pond biomass and adjusted accordingly especially during cooler periods. Moreover, an average feeding rate of 2–4 percent of shrimp biomass for *P. monodon* stocked

TABLE 4
Percent nitrogen in pond sediments (S) and discharge into the environment (DE) from shrimp ponds

Shrimp species	Percentage nitrogen in		Country
	S	DE	
Penaeus monodon[1]	57		Australia
P. stylirostris[2]	Up to 38.4		New Caledonia
P. monodon[3]	24	27	Thailand
Penaeus sp.[4]	26		-
P. monodon[5]	14–53		Thailand

Source: [1]Jackson et al. (2003); [2]Martin *et al.* (1998); [3]Funge-Smith and Briggs (1998); [4]Lin and Nash (1996) cited in Avnimelech and Ritvo (2003); [5]Thakur and Lin (2003)

TABLE 5
Nutritional composition (minimum and/or maximum levels) of commercial diets available in Indonesia for various aquaculture species

Cultured species	Percentage				
	Crude protein (min)	Crude lipid (min)	Crude fibre (min)	Crude fibre (max)	Moisture (max)
Shrimp					
Black tiger shrimp	39–42	5	3		11
Pacific white shrimp	28–42	5		3–4	11
Finfish					
Grouper	50	10		2.5	10
Milkfish	23–26	4–6		4	11
Tilapia	24–30	4–6		3–4	11
Gouramy	25–28	4–6		4	11
Catfish (*Clarias* sp)	28–32	5–7		4	11
Carp	27–30	4–6		4	11
Catfishes (*Pangasius* sp)	28–30	4–6		4	11

Source: Information obtained from different commercial feed companies (2005)

15 animals/m² may significantly reduce feed cost without affecting growth and production (Allan, Moriarty and Maguire, 1995).

Shrimp and fish aquafeeds are produced locally in several feed mills and are readily available in the market. The nutritional composition of some of the available shrimp and fish feeds is shown in Table 5 and Tables 6 and 7 illustrate factory recommended feeding rates.

Shrimp feeding

Shrimp eat slowly on the pond bottom; consequently feed should be distributed evenly and often. Hand feeding is commonly practised by walking along the pond dyke, while floating mechanical devices are used to distribute feed in the middle of the pond. Feeding trays are commonly used to monitor feeding response and shrimp health and to adjust the ration and feeding frequency. The number of feeding trays depends on pond size and is around 4–6 per hectare (Akiyama, 1989).

Shrimp feed manufacturers recommend 3–6 meals a day. However, Smith *et al.* (2002) concluded that there is no benefit in feeding *P. monodon* more than 3 times a day when using a feed that is nutritionally complete and adequately water stable.

TABLE 6

Recommended feeding rates for *P. monodon* at a stocking density of >6 PLs/m² at an assumed feed FCR of 1.7–1.8 and water stability of 2–3 hours

Culture duration (days)	Weight (g)	Feed code	Quantity of feed/day (g)	Feeding frequency (times/day)	Survival (%)	Initial feed
1–10	Pl 15–0.1	01	200	2	100	1 kg for 100 000 PLs
11–20	0.1–1	02	400	3	90	
21–30	1–3	03	600	3	80	
Culture duration (days)	**Weight (g)**	**Feed code**	**Feeding rate (%)**	**Feeding frequency (times/day)**	**% feed on tray**	**TC (hours)***
30–40	3–5	03-03SP	5.8–5.0	4	0.6	2.5
40–60	5–9	03SP	5.0–4.2	4	0.8	2.0
60–80	9–14	04S	4.2–3.6	4	0.9	2.0–1.5
80–100	14–20	04S-04	3.6–3.0	5	1.0	1.5
100–110	20–25	04	3.0–2.7	5–6	1.1	1.5
110–120	25–30	04	2.7–2.5	5–6	1.2	1.5–1.0
>120	>30	04	<2.5	5–6	1.3	1.0

* TC = time to check feed trays

Source: Information obtained from commercial feed companies (2005)

TABLE 7

Recommended feeding rates for *L.vannamei* at a stocking density of 80–120 PLs/m² at an assumed FCR of 1.4–1.6 and water stability of 2–3 hours

Culture duration (days)	Weight (g)	Feed code	Feed added/day (g)	Feeding frequency (times/day)	Survival (%)	Initial feed
1–10	Pl 8–0.1	01-02	200	3	100	1 kg for
11–20	0.1–1.5	02	400	3	90	100 000
21–30	1.5–3.3	03	600	4	80	PLs
Culture duration (days)	**Weight (g)**	**Feed code**	**Feeding rate (%)**	**Feeding frequency (times/day)**	**% feed on tray**	**TC (hrs)***
30–40	2. 5–3.5	03	5.8–4.8	4	0.6	2.30
40–60	3.5–8.0	03SP	4.8–3.2	4–5	0.8	2.0
60–80	8.0–12.5	03SP-04S	3.2–2.6	5	1.0	1.45
80–100	12.5–17.5	04S-04	2.6–2.2	5	1.2	1.0
100–120	17.5–22.0	04S-04	2.2–1.8	5–6	1.4	1.30
>120	>22.0	04	<1.8	6	1.6	1.0

* TC = time to check feed trays

Source: Information obtained from commercial feed companies (2005)

Milkfish feeding

The demand for milkfish from the domestic market and as tuna bait is increasing. The species is highly suitable for aquaculture because of its efficient use of natural food (Figure 7) and rapid growth (Boonyaratpalin, 1997). Milkfish is farmed under extensive culture conditions in organically fertilized brackish-water ponds and is often produced without the use of supplementary feeds. Under these conditions the fish feed on lab-lab (klekap), plankton and lumut (*filamentous green algae*). With adequate organic fertilization, natural food production levels range from 2 000–3 000 kg/ha/crop. Urea and TSP can be used instead of organic manure at a rate of 100 kg and 50 kg per ha during pond preparation and there after at a rate of 25 kg and 15 kg, respectively, such that water transparency is maintained at 30–40 cm (Ahmad *et al*., 2005). There is no chemical treatment for pest eradication during pond preparation. Farmers simply rely on evaporation of sea water up to 100 ppt to sterilize their ponds.

In semi-intensive culture systems, commercial feeds are applied when fish reach 100 g (after ~ 3–4 months). From this size onwards and for about one month the fish are fed a commercial feed two times per day at a rate of 1–4 percent of biomass until

FIGURE 7
Natural food (lab–lab) (left) and commercial floating feed (right) for milkfish culture in brackish-water ponds

TABLE 8
Production parameters in extensive and semi-intensive milkfish culture systems in Indonesia

Culture condition	Extensive		Semi-intensive	
	I	II	I	II
Pond area (ha)	3	4	3	4
Number of fish stocked	10 000	30 000	10 000	30 000
Initial weight (g)	0.3	0.025	0.33	0.025
Stocking density (fish/m)	0.33	0.75	0.33	0.75
Amount of initial feeding (g)	-	-	50	100
Fertilizer (kg)	1 300	1 200	300	400
Culture period (days)	240	195	152	165
FCR	-	-	1.33	1.23
Period of feeding (days)	-	-	75	75
Final weight (g)	160	150	225	285
Total harvest (kg/ha)	1 300	2 350	2 100	5 130
Survival (%)	70–90	40–70	70–90	40–70
Economic analysis				
Total cost (US$)	456	684	1 046	2 206
Cost/kg (US$)	0.35	0.29	0.50	0.43
Total income (US$)	857	1 549	1 615	4 369
Production cycle/year	1	1	2	2
Profit/year (US$)	401	865	1 138	4 326

Source: CP Fish News, special edition (2005) they reach an individual weight of 200–250 g. The fish are conditioned to sound to facilitate feeding and to improve feed utilization. A comparison between extensive and semi-intensive systems (Table 8) shows that semi-intensive milkfish culture is more profitable.

Milkfish production can be increased by using higher stocking densities and reducing the production cycle, though this practice is not economically viable for most farmers. Milkfish are often fed with "alternative" supplementary feeds such as expired bread (or industrial bakery rejects) or rice-based crackers to reduce the feed cost.

Intensive milkfish culture in offshore cages has many advantages, viz., high density 100–300 fish/m^3 high specific growth rate (1.6 percent/day); feed is used more efficiently (FCR 1.7–2.2), high productivity (350–400 kg per 6 m^3 per 6 months); easy to harvest and there is no requirement for water quality management as in brackish-water ponds (Anon., 2005).

Grouper feeding

Groupers are among the most valuable species and are cultured mainly for export. Seed production technology for various species of groupers (brown-marbled grouper *Epinephelus fuscogutatus,* greasy grouper *E. tauvina,* and humpback grouper *Cromileptes altivelis*) was established in 1995 (Murjani, Subyakto and Sitorus, 2004). Since then seed availability has become more predictable and consistent. Groupers are cultured in either brackish-water ponds or in marine floating cages. Farmers prefer to use trash fish as a feed for grouper, though there are several limitations to its use such as inconsistent supply, variable nutrient content, difficult to handle and store and the potential for disease transmission. Given the slow-growth of grouper the use of trash fish as a sole feed becomes problematic. For example, Akbar and Sudaryanto (2002) reported that *C. altivelis* in floating net cages (initial weight of 1.3 g) require 12–14 months to attain 400–500 g, while *E. fuscoguttatus* reared in ponds take 7.5 months to grow from 39 to 311 g (Komaruddin *et al*., 2005). Recent research has shown that grouper respond well to moist as well as dry formulated pellets (Martawati, 1995; Nur, Kuntiyo and Malistiyani, 2000) and prefer and perform better on a slow sinking feed (Anon., 2004). Formulated feeds are used to wean the larvae from *Artemia* at 15 days after hatching.

The results of a comparative study using a commercial dry feed and trash fish in floating net cages are shown in Table 9. The fish (1–3 g) were fed 3–5 times a day at 10 percent of biomass. For larger fish (>250 g) the feeding frequency and feeding rate was decreased to 0.5–1 times/day and 0.8 percent biomass, respectively. These results show the potential use of artificial diets, although the production costs were higher.

Common carp feeding

Common carp is one of the main freshwater fish cultured in ponds, cages, floating cages and paddy fields. Around seven strains of common carp are cultured for consumption, while another five strains are produced for the ornamental fish market. Production phases include a hatchery stage (1–3 cm), nursery phase (5–8 cm) and the grow-out phase (marketable size ca. 6–8 fish/kg). Natural food availability such as Daphnia, Moina and rotifers is important during fry and fingerling rearing and this is stimulated by using organic and inorganic fertilizers in ponds. Chicken manure at between 250–500 g/m^2 is commonly applied in combination with urea and TSP at 8–10 g/m^2 to enhance plankton production. Both floating and sinking pellets with a

TABLE 9

Survival rate (percent), daily growth rate (DGR, g/day) and food conversion ratio (FCR) of humpback grouper *Cromileptes altivelis* reared in floating net cages

Feed type	Survival rate	DGR	FCR
Dry feed -1	98.7	2.23	1.3
Dry feed -2	98.0	1.10	1.6
Trash fish	95.1	1.71	6.0

Source: Anon. (2004)

minimum protein content of 30 percent are commonly used and fish are fed at a rate of 3–5 percent of biomass per day divided into three meals (Khairuman, Suhenda and Gunadi, 2002).

Some reservoirs built for electricity generation, irrigation and flood control are now used for floating net cage culture of common carp, tilapia and gouramy. In Cirata, some 33 000 floating cage units were installed, with disastrous environmental and economic consequences (Radiarta, Prihadi and Sunarno, 2005; Trobos, 2005). In contrast, sustainable cage culture in reservoirs is conducted in Wonogori, Central Java for almost 18 years. There are a total of 400 floating net cage units and each unit (7 x 7 x 1 m^3) requires around 3 tonnes of commercial floating feed per annum for production of tilapia and carp (Krismono, 2005).

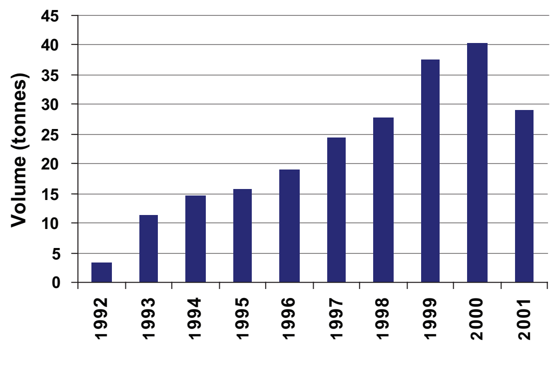
Tilapia feeding

Tilapia is an alien species and was introduced from Africa in the 1940s. There are four varieties of tilapia in Indonesia: Nile tilapia *Oreochromis niloticus*, GIFT[2] (a genetically improved Nile tilapia strain), red tilapia (a hybrid of *O. mossambicus*, *O. niloticus* and *O. aureus*) and blue tilapia *Oreochromis aureus*. The first three species/strains are more popular in Indonesia and are farmed throughout the country. Tilapia are farmed in freshwater (ponds, flow through systems, cages, floating net cages in reservoirs, lakes and rivers) and brackish-water ponds of up to 15 ppt salinity (Amri and Khairuman, 2003). Sucipto and Prihartono (2005) reported that Indonesia was the third largest tilapia producer after China and the Philippines. Tilapia is exported to the United States of America in the form of fresh and frozen fillets and whole frozen fish and the amount exported has continued to increase (Figure 8).

All male tilapia fingerlings are stocked into the production systems when they reach either 15–20 g or 30–50 g body weight. Marketable size for the domestic market is 250 g and 500–600 g for the export market, which is attained after 3 or 6 months, respectively. Culture methods are diverse and range from monoculture to polyculture with carp, java barb or catfish to integrated farming systems. Performance parameters of tilapia under different culture conditions are summarised in Table 10

A new strain of tilapia (JICA - *Jambi Initiative for Commercial Aquaculture*) was produced in 2004. In comparison to other tilapia this strain has a higher fecundity, growth rate and better FCRs than other strains.

FIGURE 8
Total volume (tonnes) of tilapia exported to the United States of America during 1992–2001



Data reported for 2001 was of seven months from January to July
Source: Ditjenkan Budidaya (2004)

Catfish feeding

Clariid catfish are mainly produced on Java Island in freshwater ponds, where it is popularly known as "*Pecel Lele*". Production has increased significantly from 28 991 tonnes in 2000 to 57 740 tonnes in 2003 (Ditjenkan Budidaya, 2004). The species responds well to various food types, is an air-breather and hence tolerant of poor water quality under high stocking densities and has a fast growth rate.

Genetic improvement through cross breeding programmes with the North African catfish, *Clarias gariepinus* has resulted in better performance of both broodstock and seed. In intensive pond culture, catfish are fed a floating or a sinking feed. Production

[2] Genetically improved farm tilapia

TABLE 10
Grow-out performance of tilapia in various farming systems in Indonesia

Performance	Ponds	Raceway (7 x 3 x 1.8 m)	Floating net cages (7 x 7 x 3.5 m)	Small cages (2 x 1 x 1 m)
Stocking				
Initial weight	15–20 g	15–20 g	15–20 g	50 g
Density	4–8 fish/m^2	300 kg/pond	200 kg/cage	5 kg/m^2
Feed and feeding				
Live food production		-	-	Natural food from the environment.
Urea	2.5 g/m^2/week			
TSP	1.25 g/m^2/ week			
Manure	250 kg/month			
Artificial feed				
Feeding rate	3–5% BW	5–6% BW	3% BW	2–3% BW
Feeding frequency	3 times/day	3 times/day	3 times/day	3–5 times/day
Crude protein	Min. 25%	Min.30%	Min. 20%	25–35%
Final weight	500–600 g	500–600 g	500–600 g	30–40 kg/m
Culture period	6 months	2–3 months	5 months	6–12 month
Survival rate	-	-	70%	-

is divided into two stages, viz. nursery and grow-out. The nursery phase starts from exogenous feeding larvae until the fish reach either 3–5 cm or 5–7 cm (1.0–2.6 g), where after they are stocked into ponds. During the nursery phase (28–38 days), commercial feeds are fed at a rate of 8–12 percent of biomass per day, divided into 4–7 meals. During the grow-out phase in ponds the feeding rate decreases from 6 percent at the beginning of grow-out to 2 percent of biomass per day at the end and feeding frequency is ultimately reduced to 2 meals a day. Catfish are low-value fish but there is a high local demand for the species. Plastic-lined ponds are used for intensive catfish production.

Gouramy feeding

Gouramy is the most expensive freshwater fish in Indonesia (US$2/kg) and is sold as a luxury food in many restaurants (Khairuman and Amri, 2003). Gouramy is cultured in extensive systems in freshwater ponds and paddy fields and intensively in floating net cages. In extensive culture systems gouramy are mainly fed on various leaves such as taro, papaya, and cassava. Floating net cages are used for intensive gouramy culture. Initial stocking size is 100 g at a stocking rate of 100 fish/m^3. Fish are fed a commercial diet *ad libitum* (4–5 times/day) with a dietary protein content of 25–28 percent. After 5 months the fish attain market size of 500 g.

2.2 On-farm pond and feed management strategies

2.2.1 Pond management techniques

Pond preparation

Pond preparation is a critical aspect of shrimp production systems. Avnimelech and Ritvo (2003) noted that nutrient accumulation in shrimp ponds result in the deterioration of the pond ecosystem. Pond sediments are therefore removed at the end of the production cycle and the ponds are allowed to dry out. Tea seed cake (10–12 ppm) and pesticides are commonly used to eliminate unwanted animals in the ponds. Lime is applied to regulate soil pH at 7.5–8.5. Recommended application rates are shown in Table 11. Liming is not recommended in areas where the soil has high pyrite content.

Ponds are filled with seawater and then sterilized with calcium hypochlorite (a.i 60 percent) at 25–30 ppm. During sterilization,

TABLE 11
Recommended lime application rate (tonnes/ha) for ponds

Soil pH	Agricultural lime	Hydrated lime
0.5–1.0	>6	1.0–2.0
5–6	2–3	1.0–1.5
<5	3–5	1.5–2.5

Source: ASEAN Cooperation in Food, Agriculture and Forestry (undated) the pond is oxygenated using a paddle wheel for 2–3 hours and then allowed to settle for 4–5 days, where after it is inoculated with *Chlorella*. Sun dried chicken manure at 300 kg/ha is sometime applied and urea and TSP are applied at a rate of 5–10 ppm. A few days after fertilization plankton blooms occur and the water becomes slightly green.

Stocking
High quality, uniformly sized, PCR negative seed (>PL_{15}) that have undergone a formalin test (200–300 ppm for 1 hour) are stocked into the ponds. *P. monodon* is commonly stocked at 10–20 PLs/m^2 and *P. merguensis* at 40 PLs/m^2, with a final survival rate after 150 days of 75 percent (Ariawan *et al*., 2004).

Feed and water quality management
Water and sediment quality are checked routinely such that they remain optimal (Chanratchakool *et al.*, 1995). Feeding regimes are adjusted routinely such that the shrimp are not overfed. Feeding trays are used to observe shrimp feeding response and growth is monitored every 10 to 30 days. Paddle wheels are used to maintain dissolved oxygen levels above 4 ppm. The number of paddlewheels depends on shrimp biomass and the general rule of thumb is that a one horse power paddle wheel can support 250 kg of *P. monodon* biomass (Taslihan, Supito and Callinan, 2004) or circa 500 kg *L.vannamei* (Tirta, pers. comm., 2005) During the production cycle of *P.monodon*, commercial feeds are applied at a decreasing rate from 20 percent at the beginning of the cycle to around 2 percent of biomass at the end of the cycle fed 2–5 times per day (Hardanu *et al*., 2004). The feeding rate for *L.vannamei* is about 50 percent of shrimp biomass at the beginning of the production cycle (Adiwidjaya *et al*., 2004).

Vibrio spp. and viruses have emerged as major constraints in shrimp aquaculture. In the past, antibiotics and other chemicals were commonly used. However, this practice has been phased out in favour of probiotics that are either incorporated into the feed or applied to the pond water (Decamp, 2004). The price of probiotics ranges from US$1.5–4.0/litre and the most commonly used brands are Super NB, Super PS and Bio-Bacter. Since 2001, probiotic application is widely used and research on the use of probiotics is on-going (Poernomo, 2004). In addition, the application of organic carbon rich substrates (glucose, cassava, sorghum meal or cellulose) to control the carbon/nitrogen ratio (C/N ratio) is one of the management measures applied in Indonesian shrimp ponds (Avnimelech, 1999; Hari *et al*., 2004).

2.2.2 On-farm feed formulation
Feed is the single most expensive item of the total production cost. The use of locally available ingredients (Table 12) for farm-made feeds must therefore be encouraged as well as appropriate fertilization regimens such that vitamins and minerals may be obtained through natural food (Brown *et al*., 1997; Trino and Sarroza, 1995).

Farm-made aquafeeds are normally manufactured using available raw material but without much regard for the composition of the ingredients and feeds are tested by trial and error. However, the number of farmers who produce their own feed is limited and most semi-intensive and intensive farmers now depend on commercial feeds. The escalating price of commercial feeds is a major constraint for farmers who produce low value fish.

2.2.3 Collection, transportation and storage of feed ingredients
Some feed ingredients such as soybean, corn, cassava, rice bran that are used in Indonesian aquaculture are readily available, though others such as *Nereis*, golden snail and *Azolla* are highly seasonal. Transportation of local ingredients is generally

TABLE 12
Proximate composition of locally available feed ingredients in Indonesia (percent dry matter basis except otherwise indicated)

Ingredients	Moisture	Crude protein	Crude lipid	Ash	Crude fibre	NFE**
Animal origin						
Fishmeal (local)[1]	8.70	55.17	4.46	19.33	1.98	18.06
Fishmeal (East Java)[2]	8.42	59.66	7.72	26.35	2.76	3.51
Fishmeal (SE Sulawesi)[2]	4.66	46.55	17.11	31.93	2.94	1.48
Fishmeal, sardine[1]	18.60	62.36	9.84	18.68	2.04	7.08
Fishmeal[1]	5.10	46.69	3.01	29.21	2.14	18.95
Krill meal[1]	11.90	60.89	1.91	29.42	1.43	6.35
Shrimp head meal[1]	11.80	41.99	1.30	37.15	2.58	16.98
Cow blood meal[1]	6.50	86.47	6.00	4.67	0.09	2.77
Fish silage[1]	79.58	59.59	7.05	23.21	2.98	7.17
Snail meal[1]	8.20	54.29	4.18	1.05	18.67	30.45
Shrimp meal[1]	17.28	53.74	8.95	4.49	24.96	10.79
Nereis meal[2]	79.08	60.06	13.96	3.58	-	-
Cow liver meal[2]	14.41	53.51	9.54	3.71	-	-
Carapax crab meal[2]	8.92	21.13	0.65	39.16	-	-
Golden snail[3]	-	54.00	-	-	-	-
Plant origin						
Soybean meal[4]	11.50	43.36	5.32	7.08	2.80	42.65
Corn meal[4]	12.10	10.81	3.66	2.00	2.00	81.59
Flour meal[4]	13.10	12.27	1.16	0.58	-	79.70
Rice bran[4]	10.10	17.11	8.67	8.00	8.68	47.44
Coconut cake meal[2]	4.28	11.85	3.14	2.37	4.45	73.91
Soybean cake meal[4]	10.52	23.86	5.93	-	26.39	42.97
**Cassava meal (fresh leaf)[4]	66.70	1.00	0.40	0.50	1.40	30.00
Azolla leaf meal[4]	8.50	25.10	3.80	23.90	12.00	35.10
Cassava leaf meal[4]	3.80	28.69	8.00		12.16	47.40
Sorghum[4]	10.64	13.00	2.05	12.60	13.50	47.85
Leucaena leaf meal[4]	9.30	14.10	3.43	1.31	18.14	28.50

*Fresh weight basis; **NFE: Nitrogen free extract.

Source: [1]Suhenda, Azwar and Djajasewaka (2003); [2]Information obtained from PSPG-UGM Yogyakarta and Environment Laboratory-CBAD, Jepara (2003); [3]Utomo, Suryana and Jusadi (2003); [4]Sucipto and Prihartono (2005)

not a major problem since most of the areas are accessed easily. However, the aquafeed industry is mainly located in Java and Sumatera and long distance transportation of commercial feeds is sometimes problematic. Inadequate storage and handling of feed (ingredients) can lead to nutrient losses, rancidity, mould and rodent infestation. Farmers are aware of these potential problems and store their bagged ingredients in well ventilated stores on wooden racks.

2.2.4 On-farm feed processing

Farm-made feeds basically consist of mixed, locally available ingredients and are made by extruding a moist cooked dough through a meat mincer. Sun-dried fish is the main source of protein, which is then normally mixed with rice bran or corn meal, molasses and tapioca meal. Farm-made feeds easily disintegrate in water and fish must be fed in such a manner that the feed is consumed quickly. Some of the larger farmers produce up to 500–600 kg feed/day using 3–5 labourers. The price of farm-made feeds ranges from US$0.15–0.18/kg. The net profit using farm-made feeds for milkfish (US$0.016–0.02/kg feed) is less than half of that for commercial pellet feeds (US$0.34/kg feed). The major constraint in making farm-made feeds is the seasonal availability of protein sources such as trash fish and sun dried fish. Other constraints are that the feeds can only be sun dried during the dry season and that it cannot be stored for long periods due to the non incorporation of antioxidants. The nutrient content of some farm-made feeds for milkfish are shown in Table 13.

TABLE 13
Proximate composition (percent as fed basis) of farm-made feeds for milkfish

Proximate analysis	Farm-A	Farm-B	Farm-C
Moisture	3.64	3.49	17.74
Crude protein	11.58	10.55	9.17
Crude lipid	7.75	12.63	5.00
Ash	13.46	8.64	12.15
Fibre	9.79	2.38	6.84
NFE	53.78	62.31	49.10

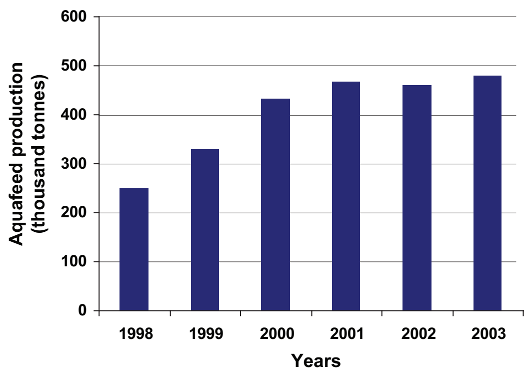
Source: Information obtained from Environment Laboratory-CBAD, Jepara, October, 2005

TABLE 14
Formulation (percent fresh weight basis) and gross nutrient composition (percent dry matter basis) of four farm-made moist feeds for juvenile grouper

Ingredients	Formulations			
	1	2	3	4
Trash fish	50	50	60	60
Fishmeal (65% crude protein)	13	12	10	11
Mussel/snail meat	-	7	-	-
Mysid meal	5	-	-	-
Soybean meal (solvent extracted)	-	-	15	-
Groundnut meal	-	-	-	15
Dry blood meal	-	10	-	-
Rice bran	16	15	9	-
Tapioca/cassava starch	-	-	-	9
Wheat gluten (80% crude protein)	10	-	-	-
Fish oil	4	4	4	3
Additives	2	2	2	2
Total	100	100	100	100
Nutrient composition (%)				
Moisture	42	47	50	50
Crude protein	29	26.5	24.5	24
Lipid	7.5	7.5	7.5	7
Ash	7.5	6.5	6.5	5.5

Source: Usman, Laining and Ahmad (2005)

FIGURE 9
Indonesian aquafeed production during 1998–2003



Source: Sukria (2004)

The technology for manufacturing a farm-made moist pellet (Table 14) for juvenile grouper has recently been developed by the Research Institute for Coastal Aquaculture (RICA), South Sulawesi. This offers many advantages for small-scale grouper farmers (Usman, Laining and Ahmad, 2005) such as, being easy to prepare with simple equipment, reducing the dependency on fishmeal, using locally available ingredients, effective vitamin enrichment, reduced feed waste and the feed can also be used to wean the fish onto dry pellets. The disadvantages are that the moist pellets cannot be stored, unless the farmer has a refrigerator, such that the feed has to be made daily and this is time and labour intensive.

3. DEVELOPMENT OF THE AQUAFEED INDUSTRY IN INDONESIA

Indonesia currently has an installed capacity to produce 12 million tonnes of animal feed. 84.5 percent of the capacity is used for the production of poultry feeds and the rest is used for the production of aquafeeds, bird and pet food (Ali Basri, pers. comm., American Soybean Association (ASA)-United States Grain Council (USGC), September 2005). Approximately 7 million tonnes of animal feed were produced in 2005, of which 595 000 tonnes (8.5 percent) comprised aquafeeds. This closely matched the estimated aquafeed requirements for 2005 (Table 15).

Aquafeed production in Indonesia continues to increase (Figure 9) because of increasing fish and shrimp production through expansion and intensification (see future projections in Table 16), the increasing use of formulated, industrially manufactured feeds by farmers and an increase in the number of aquaculture species that require formulated feeds.

To attain the future targets (Table 16) there will be a need for the increased use of locally available feedstuffs supplemented by imports. Some 70 percent and 30 percent of the ingredients for shrimp and fish feeds, respectively are imported (Widyatmoko, pers. comm., PT. Suri Tani Pemuka, 2005). Around 300 000 tonnes of aquafeed ingredients were imported in 2005. Feed ingredient imports are shown in Table 17. There was a downward trend for some ingredients and this is a consequence of the

TABLE 15
Estimation of aquafeed requirements for various cultured species in 2005 in Indonesia

No.	Species	Estimated production (tonnes)	% of production based on feed	Assumed FCR	Estimated use of feed (tonnes)
1	Black tiger shrimp	90 000	20	1.5	27 000
2	Pacific white shrimp	210 000	100	1.5	315 000
3	Milkfish	285 000	10	1.5	42 750
4	Carp	250 000	30	1.5	111 250
5	Tilapia	98 000	30	1.5	44 100
6	Clariid catfish	80 000	50	1.0	40 000
7	Others[a]	50 000	10	2.0	10 000
Total		**1 063 000**			**590 100**

[a] Grouper, seabass, gouramy, etc.

TABLE 16
Projected aquaculture production (tonnes) of various species in Indonesia for the period 2005–2009

Species	2005	2006	2007	2008	2009	% increase per year
Shrimp	300 000	350 000	410 000	470 000	540 000	15.83
Grouper	12 000	15 000	19 000	24 00	30 000	25.75
Seaweed	933 000	1 120 000	1 343 700	1 612 000	1 900 000	19.46
Tilapia	98 000	120 000	140 000	170 000	195 000	18.81
Milkfish	285 000	320 000	360 000	400 000	475 000	13.66
Asian seabass	7 200	8 200	9 500	11 000	12 500	14.79
Clariid catfish	80 000	95 000	115 000	140 000	175 000	21.64
Mud crab	6 600	7 200	7 900	8 800	9 600	9.82
Carp	250 000	270 000	310 000	375 000	446 000	15.68
Gouramy	28 400	31 300	34 400	38 000	45 000	12.25
Mussels	40 000	50 000	62 500	78 000	97 000	24.79
Pearl	12	13	15	16	18	10.72
Pangasius sp	16 500	20 000	25 300	30 300	36 500	21.98
Ornamental fishes	5 000	6 000	7 200	8 640	10 200	19.51
Others	186 288	213 027	244 285	281 744	297 382	12.48
Total	**2 248 000**	**2 625 740**	**3 088 800**	**3 625 900**	**4 269 200**	**17.39**

Source: Ditjenkan Budidaya (2005)

TABLE 17
Feed ingredient imports

Ingredient	2002		2003		Upto June 2004	
	Quantity (tonnes)	%	Quantity (tonnes)	%	Quantity (tonnes)	%
Fishmeal/crustacean meal/ meat & bone meal	294 166	67.53	29 303	39.34	118 916	80.61
Squid meal	5 776	1.32	5 182	6.96	2 631	1.78
Vitamin/mineral mixture	940	0.21	2 911	3.91	1 443	0.98
Wheat gluten/flour	128 665	29.54	24 310	32.64	15 025	10.19
Soybean/lecithin	1 096	0.25	4 523	6.07	3 747	2.54
Shrimp feed	1 283	0.29	3 865	5.19	3 063	2.08
Fish/squid oil	837	0.19	1 137	1.53	604	0.41
Filler	-	-	-	-	712	0.48
Binder	-	-	-	-	397	0.27
Others	2 795	0.64	3 263	4.38	978	0.66
Total	435 558	100	74 494	100	147 516	100

Source: Ditjenkan Budidaya (2004)

government ban (since June 2003) on imports of certain feedstuffs. In particular this relates to meat and bone meal from Canada and poultry by-product meal from the United States of America because of mad-cow disease and avian influenza and soybeans and corn from Brazil because of foot and mouth disease.

To assure that feeds are free of antibiotics such as chloramphenicol samples from feed millers, feed distributors and or farms are routinely tested (Ditjenkan Budidaya, 2005).

4. PROBLEMS AND CONSTRAINTS

Aquaculture production in Indonesia has increased steadily and there is a growing dependence on commercial feeds in semi-intensive and intensive aquaculture. Shrimp, particularly *L.vannamei,* require the most feed (around 50 percent of total estimated aquafeed production). The other 50 percent is required for semi-intensive and intensive culture of common carp, tilapia, catfish and milkfish. Production of farm-made feeds is limited and is decreasing. Tacon (2002) noted that the use of farm-made aquafeed is usually restricted to resource-poor farmers in Asia, and will in all likelihood be gradually replaced by commercial aquafeeds. Another more urgent and recent incentive for the shift to industrial feeds is to avoid the introduction and or spread of diseases from unprocessed marine food organism (including trash fish, crustaceans and molluscs). In general, farmers lack basic knowledge in the selection of ingredients, methods of preparation, dietary nutrient requirements of fish and the use of basic equipment for the production of farm-made feeds. To support the majority of extensive and semi-intensive farmers in Indonesia, there is a need for farmers to be trained in proper farm-made feed preparation methods.

Industrial feeds, especially for grow-out, are available for many farmed species. Currently, there are some 20 registered feed millers in Indonesia and most of them are located in Java and Sumatra. There is a need to increase the number of feed manufacturer in Indonesia to support the increasing aquaculture activities and developments (Poernomo-PT Matahari Sakti; Widyatmoko, PT. Suri Tani Pemuka, pers. comm., 2005). The major problems and constraints facing aquaculture feed and feeding include:

- increasing dependence of the aquafeed industry on imported feed ingredients, especially for marine protein sources and fish oil. The future increase in aquaculture production and the predicted shortage of marine resources in the coming decade will be a problem in aquafeed production (Coutteau *et al*., 2002);
- competing use of ingredients from the poultry sector and for human use;
- escalating cost of ingredients. For example, the price of fishmeal increased from US$675/tonne in January 2005 to US$710/tonne by September 2005 (Ali Basri, ASA-USGC, pers. comm., 2005). As a consequence, shrimp feed prices increased by around US$0.05/kg during the same period;
- production of farm-made feeds with locally available ingredients without considering nutrient availability and the requirements of the cultured species;
- general lack of knowledge with respect to production volumes, seasonal and geographical availability, pre-processing requirements and amino acid composition of several local feed ingredients;
- importance of role played by natural food in freshwater and brackish-water fish culture, particularly in ponds. The combined use of natural food and formulated feeds have to be managed properly so that feeding becomes more effective;
- increasing cost of organic and inorganic fertilizers and feeds as a bottleneck for the expansion of small-scale aquaculture;
- the need to further study the fate of nutrients and nutrient budgets within the captive environment to optimize feeding and minimize waste discharge into the surrounding environment;
- the need to better define the use and benefits of additives (immunostimulants, attractants and probiotics) in feeds;
- the need to train farmers in feed preparation procedures; and
- the need to define the nutritional requirements of all aquaculture species in Indonesia.

5. RESOURCE AVAILABILITY AND THE EXPANSION OF THE AQUAFEED INDUSTRY

Aquaculture production is expected to increase by approximately 17.4 percent per year from 1.47 million tonnes in 2004 (FAO, 2006) to 4.3 million tonnes in 2009. Fish and shrimp will dominate aquaculture production, though it is predicted that seaweed production will also increase significantly during this period.

New areas for aquaculture development are available (Table 18), especially for freshwater aquaculture. Milkfish and shrimp production can be increased through intensification and rehabilitating unused ponds. Mariculture for the next few years is likely to be dominated by seaweed and finfish culture.

The demand for industrially manufactured feeds will therefore also increase. Shrimp, primarily *L.vannamei,* culture is likely to expand rapidly in the country. The high feed demand of *L.vannamei* need to be addressed to produce more cost effective feeds and to minimize the use of protein sources from capture fisheries. The production of other crustacean species, such as *P. merguiensis, P. indicus, Portunus pelagicus* will also increase and this will require speciality feeds. In extensive culture systems, the availability and cost of organic and inorganic fertilizers can constraint future developments in the small-scale farming sector.

The poultry industry will require significantly more feed in future and this will no doubt impact on the availability and cost of ingredients and manufactured feeds.

6. RECOMMENDATIONS AND SUGGESTED POLICY GUIDELINES.

Aquaculture development in Indonesia has three main objectives, viz. to enhance export earnings and domestic fish consumption and aquatic resources conservation. To achieve this there is a need to address the following issues:

- The suitability of farming systems for individual aquaculture species need to be better defined on the basis of location and natural resource availability;
- Fertilizer application rates and the nutrient requirements of aquaculture species must be better defined and more information must be made available to farmers;
- Aquafeed production is too dependent on imported ingredients. There is a need to improve domestic fishmeal processing;
- Alternative protein sources must be found to replace or reduce fishmeal in aquafeeds;
- Natural food availability is important for shrimp and fish growth. Laboratory scale experiments on feed and nutrient formulations need to tested under practical farming conditions to facilitate natural food production;
- The fate of nutrients and nutrient budgets in culture systems needs to be defined to further enhance feed formulations and minimize waste to the environment;
- The use of additives (immunostimulants, attractants and probiotics) in aquaculture needs to be consolidated to improve cost efficiency; and
- Greater consumer awareness of food safety issues requires the feed industry to pay greater attention to traceability of feed materials and feed processing technology.

TABLE 18

Existing use and area available for aquaculture expansion in Indonesia

Aquaculture activity	Existing use (2003)		Area available for potential expansion	
	Area (ha)	% of total	Area (ha)	% of total
Mariculture[1]	**3 780 000**	**84.42**	**8 360 000**	**70.78**
Brackish-water	**450 000**	**10.05**	**1 220 000**	**10.33**
Freshwater	**247 473**	**5.53**	**2 230 000**	**18.89**
Pond	97 000	2.17	526 400	4.46
Paddy field	150 000	3.35	1 545 900	13.09
Common water	473	0.01	158 200	1.34

[1] Mariculture include both marine cage culture and seaweed culture

Source: Ditjenkan Budidaya (2004)

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Analysis of feeds and fertilizers for sustainable aquaculture development in the Philippines

Neila S. Sumagaysay-Chavoso
University of the Philippines Aquaculture Society, Inc.
College of Fisheries and Ocean Sciences, Miag-ao, Iloilo
Philippines

Sumagaysay-Chavoso, N.S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in the Philippines. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 269–308.

SUMMARY

Production from fisheries and aquaculture in the Philippines has increased from 2 721 000 tonnes valued at US$1 458 million in 1994 to 3 926 173 tonnes valued at US$2 777 million in 2004. In 2004, total aquaculture production reached 1 717 026 tonnes and accounted for over 44 percent of total fisheries production. Seaweed production contributes 70 percent to total production, followed by milkfish (15.9 percent), tilapia (8.5 percent) and shrimps (2.1 percent). The main species produced in land-based pond culture are milkfish, tilapia, shrimp, mudcrab and catfish.

Depending on stocking density, life support systems, fertilizer and feed inputs aquaculture systems in the Philippines can be classified as extensive, semi-intensive and intensive. Inorganic and organic fertilizers are applied in extensive and semi-intensive pond systems to stimulate growth of natural food. The most widely used fertilizers in aquaculture are mono-ammonium phosphate, di-ammonium phosphate, urea and ammonium sulphate. Except for di-ammonium phosphate the country is not self sufficient with respect to the supply of fertilizers. The most widely used organic fertilizer for ponds is chicken manure. Most farmers prefer low-cost unprocessed organic fertilizers and the use of compost is also becoming popular.

Feeding is employed when natural food, enhanced by fertilization, becomes inadequate. The aquaculture feed industry depends on local rice, corn and copra meal and imported soybean meal and wheat by-products. Fishmeal is either imported or locally sourced.

Fish farmers use commercially manufactured feeds, farm-made feeds as well as raw, unprocessed feedstuffs. Farm-made feeds or single-feed ingredients are used as feed for milkfish, shrimps, crabs and tilapia in extensive and modified extensive farming systems. Catfish are fed chopped trash fish, fresh chicken entrails and commercial swine pellets, while grouper are fed on trash fish, commercial fish pellets and live juvenile tilapia. Commercial feeds are also used in semi-intensive and intensive culture of milkfish, tilapia and shrimp.

In 2004, there were 505 registered feedmills in the Philippines. Of these, 395 were commercial feed manufactures, while the remainder were smaller, non-commercial feed producers. Of the 395 commercial feed manufacturers 78 (20 percent) produce aquafeeds. The production capacity of the aquafeed milling industry is 3.81 million tonnes/year, which far exceeds the 2003 production of approximately 204 395 tonnes. The major constraints facing the aquafeed industry are the high and volatile costs of raw materials that lead to high feed costs and reduce the demand for feed. Collectively, these factors affect fish production. Data for 2003 show that some 28 800 tonnes of commercial feeds were consumed by tilapia, milkfish and tiger shrimp. However, these figures exclude farm-made feeds, imported feeds and feed sales by the smaller feed producers.

There is an adequate local supply of organic manure to cater for the needs of the aquaculture sector in the future. Current chicken manure production exceeds 52 million tonnes, while the demand by the extensive and semi-intensive aquaculture sectors in 2003 and in the next 10 years is estimated at 489 998 tonnes.

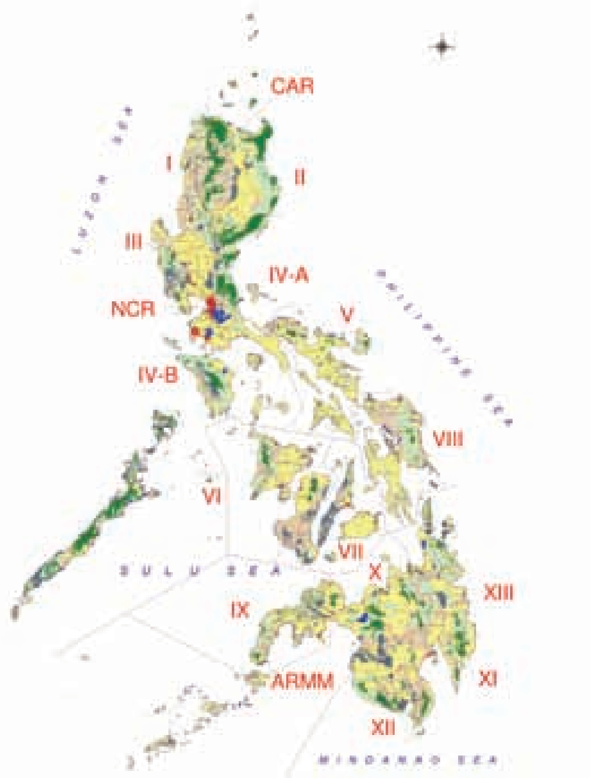
Fish production costs are significantly lower in extensive systems (US$0.47/kg), which rely mainly on fertilization and are highest in intensive systems (US$0.84/kg) due to high feed input and installation of life support systems. To sustain the growth of the aquaculture sector in the Philippines it is recommended that greater efforts be made with respect to the sourcing of raw materials for the feed industry. Also, there is a very real need to enhance farm-made feed technologies for small-scale farmers, focusing in particular on the use of local raw materials. Feed formulations must be further improved for better feed conversion efficiency and to minimize environmental impacts. Moreover, effluent volumes and composition must be regulated to minimize nutrient discharge into the environment. Government programs such as the clustering of feedmillers and fish farmers, balancing the fertilizer requirements and the rapid composting programme should be more effectively promoted and implemented.

1. OVERVIEW

1.1 Land and water resources of the Philippines

The Philippines is a tropical country in the Pacific Ocean consisting of 7 107 islands that lie between 4.23° and 21.25°N / 116° and 127°E. The islands are geographically divided into three main areas: Luzon (northern Philippines), Visayas (central Philippines) and Mindanao (southern Philippines). The country is composed of 79 provinces that are grouped into 17 administrative regions. These are shown in Figure 1 and referred to throughout the report. Luzon consists of eight regions: CAR (Cordillera Administrative Region), Region I (Ilocos), Region II (Cagayan Valley), Region III (central Luzon), Region IV-A (Calabarzon), Region IV-B (Mimaro), NCR (National Capital Region), and Region V (Bicol). Three regions are located in the Visayas: Region VI (western Visayas), Region VII (central Visayas) and Region VIII (eastern Visayas). Mindanao is divided into six regions: Region IX (western Mindanao), Region X (northern Mindanao), Region XI (southern Mindanao), Region XII (central Mindanao), Region XIII (CARAGA), and ARMM (Autonomous Region of Muslim Mindanao).

FIGURE 1
Map of the Philippines showing the 17 administrative regions



Source: NAMRIA (2005)

The country has a total land area of 29 624 660 ha, of which 11 681 040 ha are cultivated. The aquatic resources of the country are summarized in Table 1. Total fish pond area, depending on the source, ranges between 219 460 ha (NAMRIA, 2005) and 253 854 ha (BFAR, 2005; BAS, 2005a). There are approximately 239 323 ha of brackish-water and 14 531 ha of freshwater ponds (Table 1), while Table 2 provides a measure of the distribution of ponds by administrative region. Inland waters including lakes, rivers and reservoirs comprise ~250 000 ha. There are approximately 102 lakes in the Philippines, with an area greater than 100 ha. The country is also endowed with 240 million ha of coastal marine areas, including coral reefs, sea grass and algal beds. These aquatic resources support fisheries that provide income and employment, export earnings and the bulk of domestic fish supply.

1.2 Total fish production

Total fisheries production (capture fisheries and aquaculture) increased from 220 000 tonnes in 1950 to 2 721 000 tonnes (US$1 458 million) in 1994 to 3 926 000 tonnes (US$2 777 million; at $1:Php 50) in 2004 (Figure 2). The annual growth rate in fisheries production between 1994 and 2003 was 3.8 percent by volume. As a whole, the fisheries sector, which is valued at US$2 214 million at current prices, accounted for 2.3 percent of the Philippine GDP in 2004. The sector directly and indirectly employs approximately 990 000 people. In 2004, exports of fish and fishery products were valued at US$524 million, while imports were valued at US$79 million with a positive trade balance of US$445 million (BFAR, 2005).

TABLE 1
The aquatic resources of the Philippines, 2004

Resources	Area	% of		
		Marine resources	Inland resources	Country total
Marine resources (ha)				
Coastal	26 600 000	12.1	-	12.05
Oceanic	193 400 000	87.9	-	87.61
Marine Total (including EEZ) (ha)	220 000 000	100.0	-	99.66
Shelf area (ha) (depth, 200 m)	18 460 000	8.4	-	8.36
Coral reef area (ha) (within 10–20 fathoms where reef fisheries occur)	2 700 000	1.2	-	1.22
Coast length (km)	17 460	-	-	-
Inland resources (ha)				
Freshwater	106 328	-	14.2	0.05
Brackish water	139 735	-	18.6	0.06
Total swamplands	246 063	-	32.8	0.11
Freshwater	14 531	-	1.9	0.01
Brackish water	239 323	-	31.9	0.11
Total existing fish pond	253 854	-	33.8	0.12
Lakes	200 000	-	26.7	0.09
Rivers	31 000	-	4.1	0.01
Reservoirs	19 000	-	2.5	0.01
Total other inland resources	250 000	-	33.3	0.11
Inland Total	749 917	-	100.0	0.34
Country Total (ha)	220 749 917	-	-	100.00

Source: BFAR (2006); BAS (2005a)

TABLE 2
The distribution of fish ponds and inland water resources in the Philippines by region

Region	Total area (ha)	Fishponds (ha)	Inland waters (ha)
CAR	1 807 680	-	6 970
I	1 256 420	21 550	12 170
II	2 646 060	100	19 310
III	2 088 640	48 980	23 390
NCR	72 590	2 900	7 700
IV-A	1 683 750	5 850	106 660
IV-B	2 686 760	7 690	11 440
V	7 733 050	15 870	8 330
VI	1 996 950	58 720	6 850
VII	1 416 840	9 030	1 260
VIII	2 084 280	2 340	3 540
IX	1 455 430	25 010	1 770
X	1 727 020	4 150	1 620
XI	1 828 360	6 710	5 270
XII	1 928 430	3 260	10 740
XIII	1 867 470	5 830	23 640
ARMM	1 244 930	1 470	47 880
Total	**29 624 660**	**219 460**	**298 640**

Source: NAMRIA (2005)

1.3 Aquaculture

Total aquaculture production reached 1 714 860 tonnes in 2004 and continued to be the leading growth industry in the fisheries sector (BAS, 2005b). Aquaculture accounted for 32 percent of total fisheries production in 1994 and 44 percent in 2004. The substantial increases in the contribution by aquaculture to total fisheries production is largely ascribed to the rapid expansion of seaweed farming, which now contributes approximately 70 percent to total aquaculture production.

Of the 16 reported aquaculture species in the Philippines, milkfish (*Chanos chanos*), Nile tilapia (*Oreochromis niloticus*) and tiger shrimp (*Penaeus monodon*) are the three most important. Milkfish, which are mainly produced in brackish-water ponds, contributed 15.9 percent to total aquaculture production, while tilapia accounted for 8.5 percent, followed by tiger shrimp (2.1 percent) from brackish-water ponds (Table 3). Analysis of production by culture systems revealed that seaweed culture (mariculture) contributed the highest proportion (70 percent), followed by brackish-water ponds (14.8 percent) and freshwater ponds (4.4 percent). Freshwater cage and pen culture contributed 3.2 and 2.9 percent, respectively, while other minor sectors (oysters, mussels, crabs etc.) collectively

TABLE 3

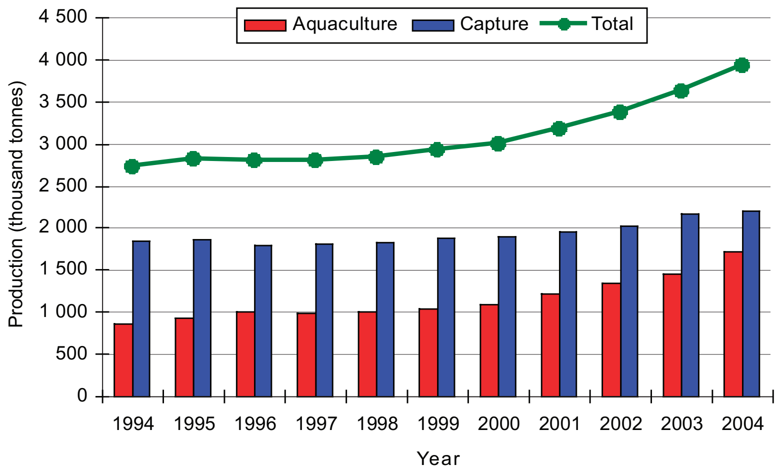
Aquaculture production (tonnes) by species and production system in 2004

Species	Production System									Total production (tonnes)	% of total production
	Pond		Pen			Cage			Mariculture		
	BW	FW	BW	FW	Marine	BW	FW	Marine			
Milkfish (*Chanos chanos*)	200 531	-	4 388	25 685	14 173	4 056	1 581	23 179	-	273 593	15.9
Nile tilapia (*Oreochromis niloticus*)	9 046	71 831	97	11 769	-	116	53 010		-	145 869	8.5
Tiger shrimp (*Penaeus monodon*)	35 916	-	-	-	-	-	-	-	-	35 196	2.1
Carp (*bighead carp, Aristichthys nobilis and common carp, Cyprinus carpio)*	-	378	-	12 541	-	-	805	-	-	13 724	0.8
White shrimp (*Penaeus setiferus*) and endeavor prawn (*Metapenaeus endeavori*)	2 030	-	-	-	-	-	-	-	-	2 030	0.1
Catfishes (waliking catfish, *Clarias batrachus* and North African catfish, *Clarias gariepinus*)	-	1 930	-	-	-	-	-	-	-	1 930	0.1
Snakehead murrel (*Channa striata*)		1 272								1 272	0.1
Grouper (*Epinephelus* sp.).		-	-	-	34	-	-	136	-	170	< 0.1
Others*	6 326	73	14	-	88	34	-	227	-	6 762	0.4
Oysters (slipper cupped oyster *Crassostrea iredale, Saccostrea* spp.)	-	-	-	-	-	-	-	-	15 915	15 915	0.9
Mussel (green mussel *Perna* viridis)	-	-	-	-	-	-	-	-	15 038	15 038	0.9
Seaweeds (*Kappaphycus* and *Eucheuma* spp.)	-	-	-	-	-	-	-	-	1 204 808	1 204 808	70.2
Total	**253 849**	**75 484**	**4 499**	**49 995**	**14 295**	**4 206**	**55 396**	**23 542**	**1 235 761**	**1 717 027**	**100**

Note: BW = Brackish water , FW = Freshwater; *Others include Mozambique tilapia (*Oreochromis mossambicus*), giant gourami (*Osphronemus goramy*), Asian seabass/barramundi (*Lates calcarifer*), orange-spotted spinefoot (*Siganus guttatus*), vermiculated spinefoot (*Siganus vermiculatus*), spotted scat (*Scatophagus argus*), Indian white prawn (*Fenneropenaeus Indicus*), banana prawn (*Fenneropenaeus merguiensis*), greasyback shrimp (*Metapenaeus ensis*), mud crab (*Scylla serrata, Scylla oceanica*), giant freshwater prawn (*Macrobrachium rosenbergii*) and lobsters (*Panulirus* spp.).

Source: BFAR (2006)

FIGURE 2
Fish production in the Philippines from 1994 to 2004



Source: BFAR (2006)

TABLE 4
Aquaculture production (tonnes) by systems in the Philippines during 2000-2004

Production system	2000	2001	2002	2003	2004
Pond					
Brackish water	235 729	268 120	254 167*	254 744*	253 849
Freshwater	45 909	57 678	70 250	71 970	75 484
Pond sub-total	281 638	325 798	324 417	326 714	329 333
Cage					
Brackish water	2 485	-	-	-	4 206
Freshwater	38 595	42 061	49 657	52 832	55 396
Marine	2 900	4 582	8 665	12 120	23 542
Cage sub-total	43 980	46 643	58 322	64 952	83 144
Pen					
Brackish water	3 241	-	-	-	4 500
Freshwater	27 529	23 927	27 468	35 876	49 995
Marine	6 296	5 738	9 113		14 294
Pen sub-total	37 066	29 665	36 581	45 949	68 789
Mariculture	738 218	818 350	919 073	1 016 888	1 235 761
Total	1 100 902	1 220 456	1 338 393	1 454 503	1 717 027

*Includes production in brackish-water cages and pens

contributed about 4.7 percent. Table 4 shows the trends in aquaculture production by systems in the Philippines during the period 2000 to 2004.

The percent contribution by production systems has remained fairly constant over this five year period. Excluding seaweeds, Region III recorded the highest production among the administrative regions and this is attributable to milkfish and tiger shrimp production in brackish-water ponds and tilapia in freshwater ponds. Region IV-A ranked second mainly due to tilapia from freshwater fish cages and pens, while milkfish production in brackish-water ponds placed Region VI in the third position.

1.4 Culture systems

Farming of fish in brackish-water ponds is a centuries old tradition in the Philippines, while freshwater ponds, as well as pen and cage culture in the freshwater, brackish-water and marine environments are later innovations. Mussels and oysters are cultured on stakes and lines are used for seaweed culture. The majority of milkfish, tilapia, shrimp, mudcrab and catfish are farmed in land-based pond systems enclosed either

TABLE 5
Overview of freshwater and brackish-water systems in the Philippines, extensive system

System	Culture species	Area (ha) or volume (m^3)	Stocking density (fish/ha)	Fertilization and feeding	Rearing period (months)	Harvest size (g)	Yield (kg/ha)
Polyculture							
Brackish-water pond	Milkfish Shrimp	1	3 000–3 500 5 000–10 000	Organic/inorganic fertilizer, supplemental feed	4	250 30	600–800 120–240
	Crab Milkfish	200	5 000–15 000 1 000–2 500	Organic/inorganic fertilizer, trash fish	4–5	200–400 250	800–4 800 200–600
	Grouper Tilapia	0.5–1.0	5 000 5 000–10 000	Organic/inorganic fertilizer, tilapia fingerlings, trash fish	5–7	400–800	1 600–3 200
Monoculture							
Brackish-water pond	Milkfish	1	1 000–4 000	Organic/inorganic fertilizers, supplemental feed, commercial feed	4	200–300	400–1 000
	Tilapia	1	3 000–5 000	Organic/inorganic fertilizer	4	100–200	300–800
	Shrimp *Extensive* *modified*	 >5 2–5	 >10 000 20 000–50 000	 Organic/inorganic fertilizers, supplemental feed, commercial feed	 3–4 3–4	 >40 28–32	 200–300 500–900
Mangrove areas	Mudcrab	200	5 000–7 000	Organic/inorganic fertilizer trash fish	3–5	150–400	800–1600
	Mudcrab fattening	200	5 000–20 000	Organic/inorganic fertilizer, trash fish	1	350–400	1 400–6 400
	Mudcrab		5 000	Trash fish		275	1 200
	Mudcrab fattening	200	5 000–20 000	Trash fish	1	350–400	1 400–6 400
Freshwater pond	Catfish	>0.1–0.5	50 000–60 000	Inorganic fertilizer, supplemental feed	4	100	3 000–4 000
Freshwater pen	Bighead carp	≥1	5 000–10 000	No fertilizer, no feed	6	1 500	4 500–9 000

TABLE 5. CONTINUED

Overview of freshwater and brackish-water systems in the Philippines, semi-intensive and intensive systems

System	Culture species	Area (ha) or volume (m^3)	Stocking density (fish/ha)	Fertilization and feeding	Rearing period (months)	Harvest size (g)	Yield (kg/ha)
Semi-intensive							
Polyculture							
Brackish-water pond	Milkfish Shrimp		10 000 35 000	Organic/inorganic fertilizer, supplemental feed, commercial feed	4	250 30	2 250 840
Monoculture							
Brackish-water pond	Milkfish	0.5–1	8000–15 000	Organic/inorganic fertilizers, commercial feed	4	200-–300	1 500–3 500
	Shrimp	1–2	100 000–150 000	Commercial feed	4–5	28–35	2 000–3 000
Brackish-water cage	Grouper	75 m^3	7/m^3	Trash fish, mussel meal, etc.	5–7	450	2.5/m^3
Freshwater pond	Tilapia	0.25–1	10 000–50 000	Organic/inorganic fertilizer, commercial feed	3–4	150–250	1 300–7 000
	Catfish	0.05	100 000–150 000		4	100	6 000–15 000
Freshwater cage	Tilapia	100 m^3	15–25/m^3	Supplemental feed, commercial feed	3–4	250–300	2.7–7.0
Freshwater pen	Milkfish	≥1	1/m^3	Supplemental feed	4	300	2 700
Iintensive							
Monoculture							
Brackish-water pond	Milkfish	0.5	≥20 000	Commercial feed	4	200–300	≥4 000
	Shrimp	<2	>200 000	Commercial feed	5–6	25–30	>3 000
Freshwater pond	Tilapia	0.5–1.0	50 000–100 000	Commercial feed	4–5	250	7 000–15 000
Freshwater cage	Tilapia	100–400 m^3	50–250/m^3	Commercial feed	3–5	150–250	5–37/m^3
	Milkfish	400	12.5–25/m^3	Commercial feed	3–5	300	3–6/m^3
Tanks	Tilapia	>0.5	100–200/m^3	Commercial feed	4–5	300	20–50/m^3

Source: milkfish - Bagarinao (1997), Sumagaysay-Chavoso (2003), author's survey (2005); tilapia - Guerrero (2002), Aldon (1998), Corpuz-Uy, pers. comm., author's survey (2005); shrimp - Regalado (2001), author's survey (2005); mudcrab - Baliao, de los Santos and Franco (1999), Rodriguez (2001), Triño *et al*. (1999); catfish - Tan-Fermin and Coniza (2003), Bombeo (2001), Surtida and Buendia (2000); grouper - Baliao *et al.* (1998), Baliao *et al.* (2000), Toledo (2001); carp - Frio (1999), Eguia (2003) with earthen or cement dykes, provided with a sluice gate for water exchange. Fish pens are large enclosures made of stakes and netting material and these are set in lakes, rivers or sheltered bays and in which the fish have access to natural benthic and planktonic food. The primary pen culture species are milkfish (marine and brackish water), tilapia (fresh and brackish water) and carp (freshwater). Fish cages are relatively small and are staked in shallow waters or set in deeper waters with appropriate floats and anchors. Tilapia, milkfish, groupers and siganids are the main cage culture species.

Table 5 provides an overview of the various freshwater and brackish-water aquaculture systems in the Philippines and their mode of operation. The data clearly show how stocking density, fertilization, feeding intensity and the complexity in life support systems increase with systems intensification.

2. REVIEW AND ANALYSIS OF AQUACULTURE FEEDS AND FEEDING

2.1 Fertilizer and feed resources of the Philippines

2.1.1 Fertilizers

Inorganic fertilizers

The most widely used fertilizers in aquaculture are mono-ammonium phosphate (16-20-0) and di-ammonium phosphate (18-46-0) as nitrogen and phosphorus sources, urea (46-0-0) as a nitrogen source and ammonium sulphate (21-0-0). Ammonium sulphate in combination with lime is used to kill unwanted species in ponds prior to stocking.

Though some fertilizers are produced locally the bulk is imported. Table 6 shows the 2003/04 supply and demand for inorganic fertilizers commonly used in aquaculture. Urea dominated the country's fertilizer imports averaging 35.4 percent in 2003 and 2004 followed by 21-0-0 (22.8 percent) and 18-46-0 (8.1percent). Fertilizer exports, on the other hand, decreased from 456 636 tonnes in 1997 to 21 356 tonnes in 2004, due to a decrease in domestic demand (Cipriano, 2002).

Average sales in 2003 and 2004 were dominated by 14-14-14 (30.0 percent), urea (25.1 percent), 16-20-0 (17.3 percent) and 21-0-0 (11.9 percent). Since 2002 there have been five companies that produce fertilizers and which have blending facilities. These are Philphos, AFC Fertilizer and Chemical Inc., International Chemical Corp (INCHEM), Farmix Fertilizer Corp., and Soiltech Agricultural Products Corp. (Cipriano 2002; FADINAP, 2002)

Government support for the fertilizer industry is historically strong. The deregulation of the fertilizer industry in 1986 encouraged the entry of more traders. This fostered competition to the benefit of consumers (ADB, 2002). Quality assurance and monitoring systems are being institutionalized. Government support is

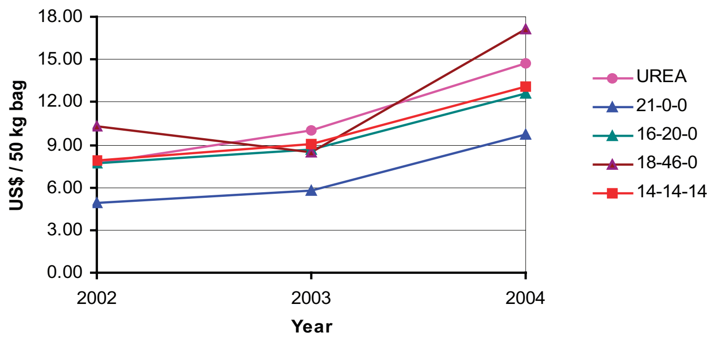
TABLE 6

Domestic supply and demand (tonnes) of inorganic fertilizers commonly used in aquaculture

Grade	Import	Production	Sale	Export
2003				
Urea	733 683	-	466 413	1 600
21-0-0	398 620	116 656	212 053	58 176
16-20-0	63 170	203 755	252 621	19 390
18-46-0	163 911	65 820	32 000	36 500
14-14-14	43 200	368 543	416 980	-
Total	**1 640 386**	**1 059 315**	**1 540 179**	**334 944**
2004				
Urea	426 190	-	172 333	-
21-0-0	348 206	33 780	86 568	500
16-20-0	91 106	83 106	158 666	-
18-46-0	103 193	43 937	18 087	15 096
14-14-14	58 455	122 730	286 946	-
Total	**1 639 752**	**371 404**	**869 513**	**21 356**

Source: FPA (unpublished report)

FIGURE 3
Average retail prices of major fertilizer grades



Source: FPA (unpublished report)

manifested through price control and incentives (ADB, 2002). A tariff of 3 percent is set on 21-0-0, 18-46-0, and 16-20-0, and 1 percent on urea for MFNs and free for ASEAN member countries (Philippine Tariff Commission 2004). A 10 percent value-added tax exemption is also granted to direct users (cooperatives, farmer's associations, partnership and other entities directly involved in agriculture or fisheries) by way of value-added tax exemption certificates approved by the FPA. This incentive is in line with the R.A. (Republic Act) 8435, otherwise known as the Agriculture and Fisheries Modernization Act (Arboleda, 1998).

In 2003/04, 18-46-0 was the most expensive (US$199–242/tonne), followed by urea (US$171–240/tonne). World prices and currency exchange rate fluctuations influence the domestic prices of inorganic fertilizers. Between 1995 and 2001, inorganic fertilizer retail prices increased annually by 4.0–5.5 percent. However, at real or constant prices, the retail price actually declined by 6.7–7.6 percent during this period. (*Real or constant prices are determined after the effects of inflation have been eliminated. Nominal prices refer to the current value of a good or commodity during a particular period or year.*) However, between 2002 and 2004 the retail price of 16-20-0 increased by 64 percent and by 97 percent for 21-0-0 (Figure 3). It is for this reason that farmers are now seeking alternatives and are looking more towards organic fertilizers.

Organic fertilizer (manures and compost)

The FPA of the Department of Agriculture has recently formulated guidelines on good agricultural practices to optimize fertilizer use. In particular, the guidelines advocate the use of organic fertilizers to promote sustainable production and development. The most widely used organic fertilizer in ponds is chicken manure at prices ranging from US$16–22/tonne. Other livestock manures, mudpress (agricultural waste from sugar mills) and rice bran are also used but to a much lesser extent. Fish farmers usually apply organic fertilizers during pond preparation, although some apply manure during the production cycle to maintain plankton growth. It was estimated that between 56.8 million and 107.8 million tonnes of manure was produced in 2004 (Table 7).

TABLE 7
Estimated animal manure production

	Animals (tonnes live weight)[1]		Dry manure production (tonne/year)	
Year	2003	2004	2003	2004
Carabao[a]	132 384	138 048	174 868–347 926	182 350–362 812
Beef cattle[b]	129 225	127 990	170 695–339 624	169 064–336 378
Dairy cattle[c]	129 255	127 990	320 790–528 415	317 651–523 244
Swine[d]	1 733 087	1 709 404	3 767 346–7 155 146	3 715 864–7 057 369
Chicken[e]	1 188 738	1 231 794	50 557 544–96 021 604	52 388 734–99 499 499
Total			54 991 243–104 392 716	56 773 663–107 779 303

[a] Manure production based on assumption for beef cattle; [b] Total solids in waste: 1 643–3 269 g/day/454 kg animal; [c] Total solids in waste: 3 087–5 085 g/day/454 kg animal; [d] Total solids in waste: 268–509 g/day/45 kg animal; [e] Total solids in waste: 268–509 g/day/2.3 kg animal

[1] Total production by region and by quarter, 1999-2004

Source: BAS, unpublished report

TABLE 8
Distribution of fishponds and livestock in the Philippines in 2004

Region	Fishpond area[1] (ha)	Animals (tonnes live weight)[2]			
		Carabao	Cattle	Swine	Chicken
CAR	none	4 766	6 492	40 588	7 478
I	21 550	9 062	30 505	77 235	51 082
II	100	13 889	15 390	96 714	53 520
III	48 980	5 216	17 575	267 095	384 072
IV-A	5 850	5 019	19 706	213 742	283 725
IV-B	7 690	8 081	10 580	55 086	7 330
V	15 870	9 968	13 700	95 132	29 874
VI	58 720	17 326	25 106	139 351	63 711
VII	9 030	5 305	31 086	130 564	81 185
VIII	2 340	7 912	3 598	112 410	38 305
IX	25 010	9 947	16 343	93 659	28 027
X	4 150	7 423	28 103	102 000	57 782
XI	6 710	10 289	11 091	128 112	88 777
XII	3 260	14 127	14 511	91 581	32 943
XIII	5 830	3 644	1 482	59 251	15 310
ARMM	1 470	6 074	10 713	6 884	6 884

Source: [1] NAMRIA (2005); [2] total production by region and by quarter, 1999-2004 (BAS, unpublished report)

TABLE 9
Specifications for organic fertilizers and compost/soil conditioners

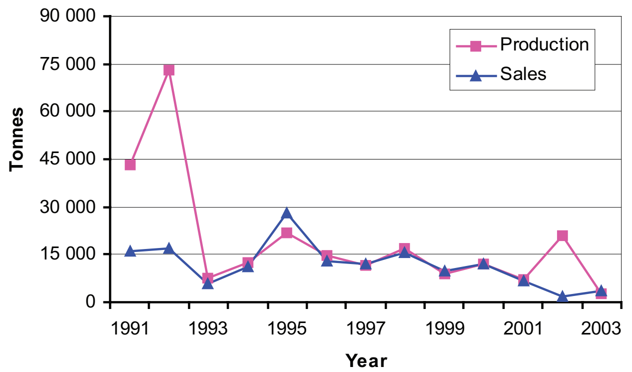
	Pure organic fertilizer	Compost/soil conditioner	Fortified organic fertilizer
Total NPK	5–7%	3–4%	8% minimum
C:N	12:1	12:1	12:1
Moisture content	≤35%	≤35%	≤35%
Organic matter	≥20%	≥20%	≥20%

Source: FPA (unpublished report)

The demand for chicken manure by tilapia farmers in Central Luzon (Region III) and by milkfish farmers in Region IV is particularly high (Table 8) (ADB, 2002). As mentioned earlier, most farmers prefer low-cost unprocessed organic fertilizers of animal origin, but the use of compost is also becoming popular. Compost is commonly made from rice hulls, rice straw, grasses, hog and chicken manures, leucaena leaves or other leguminous material. Bacteria or fungi are usually added as activators (Cuevas, 1997). Other techniques include vermicomposting (Dugeno 2005). All commercially produced composts must also conform to regulatory standards (Table 9).

Production of composted organic fertilizers began in 1974 (Cuevas, 1997). Highest production levels were attained in 1992 when some 75 000 tonnes were produced but by 2003 had decreased to less than 5 000 tonnes per annum. Production again increased to 19 000 tonnes in 2004 (Figure 4).

FIGURE 4
Domestic organic fertilizer supply and demand



Source: FPA (unpublished report)

Marketing of fertilizers. The market chain for inorganic fertilizers starts with the producers or importers to the distributors (wholesalers) in regional or provincial sale offices. The distributors transfer the products to local dealers and retailers who sell directly to farmers. Dealers are distributed throughout the country and in isolated areas play a particularly important role. Fertilizer companies advertise their products through sponsorship of related activities and distribution of promotional items (ADB, 2002).

Several importers are also distributors, giving them an advantage in terms of direct access to retailers. At the wholesale level, some distributors are authorized dealers themselves and sell directly to plantations and/or farmers in areas where local dealers may be absent. In some instances, traders access cooperatives to distribute fertilizers to their farmer-members. The geographical isolation of most Philippine islands adds to the marketing and distribution costs (ADB, 2002). Organic fertilizers, on the other hand, are usually sold in the area where they are produced.

2.1.2 Availability of feedstuffs and their use in aquaculture

Most of the high quality feed ingredients are imported, though efforts are being made to partially or fully replace these with locally produced materials. There are many locally available raw materials that are either used or have potential as ingredients for aquafeeds (Table 10). The major feedstuffs used are fishmeal, rice bran, soybean meal, copra meal, wheat flour, coconut oil, soybean oil and fish oil. Rice, corn and copra meal are produced locally, while soybean meal and wheat by-products are imported. Fishmeal is either imported or locally sourced. Import and export figures of agricultural products and by-products used by the animal feed industry are shown in Tables 11 and 12.

To foster efficiency and global competitiveness, individual farmers as well as farmer associations or cooperatives are eligible for exemption from value-added tax on all types of agricultural products including feed ingredients like fishmeal, wheat, and soybeans. To be eligible, the imported products must be exclusively consumed by the enterprise and may not be sold. Eligibility for the certificate of exemption is determined and approved by the Department of Agriculture (DA). Exporters from MFN are charged a 1 percent tariff for fishmeal, starch residues, and shrimp feeds; 3 percent for rice bran, wheat and soya; and 10 percent for copra, corn bran and corn germ. ASEAN member countries are exempted from paying tariff duties (CEPT - Common Effective Preferential Tariff for ASEAN countries) except for the export of some products such as rice bran (3 percent), corn bran (5 percent), corn germ (5 percent), and copra (3 percent) (Philippine Tariff Commission, 2004).

Fishmeal

The country is heavily dependent on imported fishmeal especially from the United States of America, Peru and Chile. Imports decreased from 84 546 tonnes in 2001 to 44 567 tonnes in 2003. Most of the local fishmeal is obtained from Mindanao and is preferred by feedmills because of the lower cost.

Agricultural by-products

The availability and use of domestic agricultural by-products for animal feed is increasing. This is due to increased agricultural output, particularly of rice and corn (Table 13). However, seasonal supply and price fluctuations are substantial. After rice, corn is the second most important agricultural product in the Philippines. About 43 percent of the world copra production is produced in the Philippines. Copra meal and oil are used in aquafeeds.

Livestock

By-products of slaughtered livestock and poultry dressing such as blood meal, poultry by-product meal and feather meal are potential components for animal feeds. Meat and bone meal is already used in the formulation of some commercial aquafeeds. Slaughtered livestock and poultry (Table 14) registered a positive average growth per year from 2000-2004, except for cattle and goats.

TABLE 10
Available and potential aquaculture feed ingredients in the Philippines

Ingredients and recommended inclusion levels	Description
Animal by-products	
Fishmeal Carnivorous fish: 50%; omnivorous/ herbivorous fish: 25%; penaeid shrimps: 25%	A high quality protein feedstuff; excellent source of amino acids; high ash content; rich in water soluble vitamins but low in fat soluble vitamins. High cost is limiting its use and local fishmeal is of low quality.
Blood meal: <5–10%	High in leucine, lysine and iron. Included into some Nile tilapia and grouper diets at 10% and 15% of total protein.
Feather meal (hydrolysed): 5–10%	Contains up to 87% protein, deficient in some essential amino acids; digestibility decreases as processing pressure increases. Digestibility by grouper is high (74%)
Meat and bone meal: 15–20%	Can replace up to 25% of fishmeal in diets of Nile tilapia and 8% of shrimp head meal protein in diets of milkfish fry.
Poultry by-product meal Carnivorous fish: 25%; omnivorous fish: 35%; crustaceans: 15% max	Contains about 61% protein; good source of essential amino acids, iron, zinc and choline.
Shrimp meal Carnivore: 20%; omnivore/herbivore: 10%	Rich in highly unsaturated fatty acids; good source of choline; calcium and phosphorus; with chemo-attractant properties; commonly used in crustacean feed rather than in fish feed; limited inclusion levels due to high crude fibre, ash and chitin.
Squid meal Grower and finisher feed: 5–10%; broodstock feed: 20–30%; larval food: 20–30%	High protein level, well balanced amino acid profile; with chemo-attractant (glycine and betaine) and growth promoting properties; excellent ingredient in aquafeeds; fresh squid is also recommended in moist diets.
Rice by-products	
Rice bran Omnivorous & herbivorous fish: 35%; carnivorous fish: 15%; crustaceans: 10%	An energy feedstuff; contains 12–15% oil; high levels of unsaturated fatty acids causes rapid deterioration; contains high phytate phosphorus, iron and manganese; rich in B group vitamins; used more often in diets of omnivorous and herbivorous fish.
Rice hull Omnivorous fish: 5%; herbivorous fish: 10%	Suitable for feeding in extensive production system; may serve as feedstuff or fertilizer in low density milkfish culture or as supplemental food in diets of grass carp
Wheat and wheat products	Relatively low in protein (13–16%); low in calcium but high in phosphorus; good source of Vitamin B; high protein and fat digestibility.
Wheat gluten Fish feed: 2–5%; crustacean feed: 5–10%	By-product of starch manufacture from wheat.
Wheat pollard Fish feed: 10–20%; crustacean feed: 3–5%	Used as binder for shrimp feeds.
Wheat flour Wheat flour as binder in shrimp diet: up to 25%	An energy source and common pellet binder for shrimp feeds
Maize products	
Corn starch Carnivorous fish & crustaceans: 15%; omnivorous & herbivorous fish: 35%	Product of wet milling of maize; can be gelatinized to improve digestibility; serves as energy source and spares protein.
Corn gluten meal Carnivorous fish/crustaceans: 10–15%; omnivore/herbivore: 20%	By-product of wet milling in the processing of starch; protein portion of corn kernel
Corn bran Carnivorous fish: 5%; omnivorous/ herbivorous fish: 20%	Outer coating of corn kernel; contains hulls and other parts of the kernel not separated from the starch; about 21% of corn kernel is corn bran.
Pulses	
Cow pea, lupin, feed pea Treated seeds: $\leq$ 15% Untreated seeds should not be used	Dehulled lupin can replace up to 50% protein of soybean meal in tiger shrimp diet; feed pea can replace 20% protein in milkfish diet and 25% in tiger shrimp diet; cowpeas must be dehulled for inclusion into shrimp feeds.
Oilseed meal and cakes	
Copra meal/cake Herbivorous & omnivorous fish: 5–15%; carnivorous fish: 5–10%	Copra meal is a protein feedstuff; limiting in lysine and methionine; coconut cake contains higher fat than the meal; cake is more prone to rancidity; meal and cake contains high choline and phosphorus but low in calcium. More suitable for herbivores and omnivores than carnivores.
Soybean meal Fishes: carnivore: 5–15%; omnivore/ herbivore: 10–30% Crustaceans: marine shrimps: 15%; freshwater shrimp: 20%	High protein content with best amino acid profile of all vegetable meals and oilseed cakes; methionine and cystine limiting; contains trypsin inhibitor and urease which is deactivated by heat treatment. Can replace 50% of fishmeal in diets of tilapia; 67% of fishmeal in milkfish diet with methionine supplement; 15–55% of fishmeal in diets of tiger shrimp cultured in ponds at 10 to 20 shrimps/m^2

TABLE 10 CONTINUED

Available and potential aquaculture feed ingredients in the Philippines

Live food	
No standard formula; varies with species, density and larval stage	Several live feeds (phytoplankton and zooplankton) are cultured and used in Philippines and include *Chlorella*, rotifers, *Daphnia*, *Moina*, copepods and *Artemia* (imported).
Leaf and leaf meal	
Cassava leave	Potential source of low cost plant protein, high lysine content but low in methionine; can supplement cereals in fish diets that are deficient in lysine. Good performance by milkfish at inclusion of 13%.
Leucaena leaf meal (ipil-ipil) 5–10% only for herbivorous and omnivorous species	Processed dried leaves of tropical legume; fresh leaves contain mimosine, a toxic glycoside, which can be reduced and removed through soaking, sun-drying and heat treatment; good quality protein (29%); Nile tilapia and tiger prawn respond better to soaked than unsoaked leaves.
Oil	
Fish oil: 3–6%	Crude fish oil is obtained from manufacture of fishmeal.
Beef tallow: 5–10%	An energy source with high levels of saturated fatty acids (48.2%) and unsaturated fatty acids (46.6%); cholesterol content is 1 000 mg/kg. Incorporated into milkfish diets.
Coconut oil	Milkfish performance improved with equal amounts of coconut oil (5%) and fish oil (5%).
Soybean oil	Combination of fish oil and soybean oil at 1:1 ratio is best for milkfish and seabass; practical diets for tiger shrimp may contain 2.5% soybean oil and 2.5% fish oil for good performance in grow-out systems.

Source: Devendra (1985); Sumagaysay and Borlongan (1995); Hertrampf and Piedad-Pascual (2000); Eusebio, Coloso and Mamauag (2004)

TABLE 11

Volume of imported agricultural products used by the animal feed industry, 2004

Commodity description	Quantity (tonnes)
Flours, meals and pellets of fish, unfit for human consumption	44 125
Flour, meals and pellets of crustaceans, unfit for human consumption	1 215
Flour, meal and pellet of meal, meat offal, unfit for human consumption	11 281
Wheat used as feed	198 581
Wheat, corn, rye, rice and other cereal flours	15 488
Groats (hulled grain) and meal of maize and other cereals	192
Tapioca and substitutes prepared from starch	1 193
Bran and other residues from maize, rice and wheat	47 190
Oil cake and other solid residues (except dregs[1]), pellet form	1 213 827
Soybean	284 139
Sunflower, sesame, rape/colza, mustard, copra, palm and kernels, linseed, other oil seeds and oleaginous fruits	49 840
Flour and meal of soybeans, non-/partially-/wholly defatted	2 149
Flour and meal of oil seed/oleaginous fruits	37
Residues of starch manufacture and similar residues	61 785
Wheat, maize, potato, manioc (cassava), and other starches	108 654
Wheat gluten; casein and casein derivatives and the casein derivatives; protein isolates	5 330
Dextrin, soluble or roasted starch; esterified or etherified starches; other modified starches	24 139
Cod liver oil, fats and oils of fish other than liver oils	170
Lard, poultry and pig fat; pig fat free of lean meat; animal tallow	23 318
Other fats of bovine animals, sheep and goats, raw/rendered; lard-/oleo-strearin, lard tallow oils; animal oils and fats and their fractions, refined or not	9 498
Soybean oil and its fractions, crude and refined	14 481
Active natural and inactive yeasts, other single-cell microorganisms	4 699
Bagasse and other waste of sugar manufacturing	21
Brewing and distilling dregs and wastes	506
Brine shrimp eggs	7
Prawn feeds	34 890
Feed additives	19 822
Feed supplements	1 984
Other preparation used for animal food	3 365

[1] Product of processing, precipitate

TABLE 12
Volume of exports of agricultural products, 2004

Commodity Description	Quantity (tonnes)
Flours, meals and pellets of fish, unfit for human consumption	267
Rice, semi- or wholly-milled	983
Maize seed (not including sweet corn), un-milled	137
Flour of wheat, enriched or not	1 785
Rice flour, other cereal flour, flour and meal of potatoes	82
Tapioca and substitutes, prepared from starch	112
Flour, meal and powder of dried leguminous vegetables	0.02
Meal and powder of cassava, vam, sago pith and other roots and tubers	44
Flour, meal and powder of coconut	816
Maize, cassava, and other starches	13
Wheat used as feed	63
Wheat gluten	502
Desiccated coconut	105 829
Copra	38
Soybean	0.15
Cotton, sesame seeds	616
Oilcake and other solid residues from extraction of oil from coconut/copra	364 245
Oilcake and meal of other solid residues (except dregs), ground or pelleted	566
Corn cobs after removal of grain; corn stalks and leaves, hydrolyzed	4 168
Waste fruit (peel and cores) and fruit pomace (pulpy residue)	6 682
Other vegetable residues and by-products, vegetables materials and wastes	552
Bran, and other residues of maize, rice, other cereals	1 649
Tobacco refuse	2 268
Bagasse and other waste of sugar manufacturing	710
Brewing and distilling dregs and waste	6
Shark liver oil and fats; oils of marine mammals, and their fractions	34
Lard; other pig and poultry fat; animal tallow	22
Soybean oil and its fractions, refined	7 049
Coconut (copra) oil, crude, refined and its fractions	959 400
Preparations for making complete/supplementary feeds (premixes)	1 393
Prawn feeds	138
Feed additives	0.66
Other preparation used for animal food	4 572

The available agricultural by-product resources for use in aquafeeds in 2004 and a forecast of requirements for 2014 are presented in Table 15. The forecasts were estimated from current production rate increases and the average percent by-product. The data suggest that the Philippines have adequate resources of energy-rich feedstuffs to cope with the future expansion of the sector.

TABLE 13
Major crop production in the Philippines (tonnes)

Crop	1999	2004	% annual average growth over 5 year period (1999-2004)
Rice	11 786 625	14 496 784	4.25
Corn	4 584 593	5 413 386	3.66
Soybean	NA	974	0.72
Coconut	11 589 010	14 336 618	4.42
Sugar cane	23 777 828	25 579 214	1.77
Cassava	1 890 315	1 640 520	-2.74

NA: data not available
Source: BAS (unpublished report; 2006)

TABLE 14
Livestock and poultry production

Animal	Number of heads			Production (tonnes) (2004)	% annual average growth over 5 year period (1999-2004)
	2002	2003	2004		
Carabao	281 189	277 138	280 960	40 626	5.0
Cattle	660 136	649 079	595 717	78 068	-3.3
Horse	2 974	4 822	11 284	1 571	54.2
Swine	8 522 092	8 944 878	9 118 437	502 841	4.9
Goat	97 599	89 872	87 813	1 197	-2.5
Chicken	228 145 975	186 747 121	221 743 933	255 119	7.1

Source: BAS (unpublished report)

TABLE 15

Available feed resources (raw materials and by-products) in the Philippines in 2004 and forecasts of by-product availability in 2014 (tonnes)

Feedstuffs	Raw material (2004)	By-product (%)*	By-product (2004)	Growth of raw material (%/year)	By-product (2014)*
Common feedstuffs					
Rice bran	14 496 784	10	1 449 678	4.2[e]	2 058 543
Corn bran	5 413 386	21	1 136 811	3.7[e]	1 557 431
Corn starch	5 413 386	69	3 735 236	3.7	5 117 274
Cassava flour	1 677 564	62	1 040 090	3.7[e]	1 424 923
Total (energy sources)	**27 001 120**		**7 361 815**		**10 158 171**
Coconut oil	14 366 184	10	1 436 618	4.4[e]	2,068,730
Soybean oil	974	19	185	0.7 [e]	198
Total (oils)	**14 367 158**		**1 436 803**		**2 112 027**
Copra meal/cake	14 366 184	4.9	703 943	4.4	1 013 678
Soybean meal	974	82	799	0.7	855
Shrimp head meal	17 958[a]	40	7 183	-0.8	6 609
Meat and bone meal	624 303[b]	39	243 478	2.3[f]	299 478
Fishmeal (local)	no record of local production				
Potential feedstuffs					
Poultry by-product meal	255 119[c]	18	45 921	7.1[g]	78 526
Feather meal	255 119[c]	9	22 961	7.1[g]	39 263
Blood meal	624 303[b]	7.5	46 823	2.3[f]	57 592
Leucaena leaf meal	2 907[d]	19.8	576	11.8[h]	1 255
Cassava leaves	1 677 564	12	201 308	-2.7	146 955

*Amount of raw material x % by-product

[a] Assuming that 50% of shrimp production (35 916 tonnes) is processed, shrimp production growth from 1998-2004; [b] Total weight of slaughtered livestock (cattle, carabao, horse, hog, goat) in abbatoirs; [c] Weight of slaughtered chicken in poultry processing plants; [d] Log production in 2003 (Philippine Forestry Statistics, FMB-DENR); [e] Based on increase crop production, 1994-2004; [f] Based on the increase number of slaughtered livestock (carabao, cattle, swine, goat) in abbatoirs, 1994-2004; [g] Based on the increase number of slaughtered chicken in poultry processing plants, 1994-2004; [h] Based on log production from 1999-2003 (Philippine Forestry Statistics, FMB-DENR), no available data yet for 2004

Source: (for estimates of % by-products of raw materials): Blair (1990) (leucaena leaves); Devendra (1985) (cassava leaves); Hertrampf and Piedad-Pascual (2000) (other feedstuffs)

2.1.3 Nutritional value of feedstuffs

The choice of ingredients for feed formulation depends on their nutrient content, digestibility, presence or absence of anti-nutritional factors, availability and price. The proximate composition of some feed ingredients is shown in Table 16. Feedstuffs containing protein with a good amino acid profile are usually expensive and their use is constrained by price. The bio-availability and digestibility of nutrients present in feedstuffs vary between species and influences the level of inclusion in feed formulations. The digestibility of various feedstuffs by Philippine aquaculture species are listed in Table 17. Fishmeal and soybean meal digestibility in milkfish varies with salinity (Ferraris *et al*., 1986).

2.1.4 Nutrient requirements

Tables 18, 19, and 20 list some of the known nutrient, vitamin, and mineral requirements of fish and crustaceans cultured in the Philippines. These data are used as a guide by commercial and non-commercial feed manufacturers in formulating feeds.

2.1.5 Commonly used feedstuffs

Omnivorous fish. Milkfish larvae in hatcheries are fed flaked microbound diets in combination with *Brachionus* (zooplankton) and copepod (*Acartia* and *Pseudodiaptomus)* nauplii. In extensive grow-out systems, milkfish are only fed on commercial feeds or on single, energy rich ingredients such as rice bran, corn bran and / or biscuit and noodle factory rejects during the last month of culture.

Tilapia broodstock, larvae and fry are fed on rice bran or a combination of rice bran and fishmeal. Locally available feedstuffs such as rice bran, wheat pollard, copra meal,

TABLE 16

Proximate composition (percent dry matter) of selected feed ingredients available in the Philippines

	Moisture	Crude protein	Crude lipid	Crude fibre	NFE**	Ash
Feed ingredients of animal origin						
Fishmeal (local)	10.3	64.1	6.5	0.8	8.5	20.1
Fishmeal, Chilean	8.4	70.1	8.5	0.5	4.1	16.8
Fishmeal, Danish	9.5	73.9	9.4	0.3	2.4	14.0
Fishmeal, Peruvian	7.7	68.1	8.0	1.1	5.9	17.0
Fishmeal, tuna	9.4	65.4	8.0	0.8	8.8	17.0
Fishmeal, white	7.2	69.0	7.6	0.6	4.8	18.0
Meat soluble	4.2	76.5	1.2	0.2	10.3	11.8
Poultry feather meal	4.8	70.9	17.7	0.6	8.3	2.5
Prawn head meal	6.5	51.2	5.2	13.3	5.3	25.0
Shrimp meal, *Acetes* sp.	8.2	68.6	3.9	3.6	7.6	16.3
Squid meal	6.9	78.5	5.5	1.3	6.7	8.0
Squid meal, scrap	5.5	74.1	7.1	0.9	8.1	9.8
Blood meal	6.3	87.7	3.0	0.4	3.3	5.6
Meat and bone meal	5.6	46.8	9.6	2.0	7.5	34.1
Feed ingredients of plant origin						
Corn germ meal	4.5	47.4	8.5	6.4	36.9	0.8
Corn gluten meal	8.0	60.6	7.0	3.4	27.8	1.2
Leucaena leaf meal, giant	7.8	25.1	6.8	10.6	44.0	13.5
Leucaena leaf meal, native	10.3	29.3	8.8	11.5	43.5	6.9
Copra meal	7.9	22.0	6.7	17.3	44.3	9.7
Corn meal	8.4	7.8	4.7	2.6	83.1	1.8
Corn starch	11.9	0.4	0.2	1.1	98.2	0.1
Flour, bread	12.1	12.9	1.2	0.3	84.9	0.7
Flour, whole wheat	11.3	15.3	1.7	0.8	81.1	1.1
Germ, wheat	6.0	27.8	4.3	3.4	59.6	4.9
Gluten, corn	7.3	62.6	7.7	2.2	25.9	1.6
Gluten, wheat	8.9	80.7	1.4	0.4	16.4	1.1
Rice bran	9.2	13.3	14.1	8.5	53.4	10.7
Rice bran, tiki-tiki	10.7	18.0	2.0	8.0	62.4	9.6
Rice hull	7.0	3.3	2.0	32.4	41.6	20.7
Soybean meal, full fat	5.6	35.8	19.8	4.9	33.9	5.6
Soybean meal, defatted	8.4	43.6	1.5	5.5	41.7	7.7
Soy protein concentrate	5.7	56.9	1.0	5.1	28.7	8.3
Wheat flour	13.2	10.9	1.1	0.6	86.9	0.5
Wheat, pollard	9.5	15.4	4.5	10.3	64.0	5.8
Feed ingredients of other sources						
Casein	7.2	89.7	0.1	0.3	8.9	1.0
Crab meal	4.2	37.9	4.1	10.7	8.9	38.4
Gelatin	7.9	94.4	0	0.1	5.1	0.4
Frog meal	7.6	62.5	1.7	1.2	4.7	29.9
Mussel meal, green	5.9	64.6	8.6	3.0	12.5	11.8
Oyster meal	4.4	54.6	9.4	4.0	20.1	11.9
Scallop meal	7.3	65.2	10.9	1.4	8.8	13.7
Snail meal, kuhol	4.0	52.1	1.8	2.1	15.7	28.3
Yeast, Brewers	7.2	49.4	1.6	2.4	34.5	12.1
Yeast, Candida	8.3	55.2	0.8	1.7	35.1	7.4
Natural food						
Acartia sp.	7.8	71.2	8.3	5.4	9.9	5.2
Artemia	8.0	55.5	6.8	11.3	15.0	11.4
Azolla	8.0	27.2	3.4	12.9	36.5	20.0
Brachionus sp.	8.1	51.9	10.4	3.5	15.3	18.9
Chaetoceros calcitrans	7.6	24.4	7.1	2.5	26.7	39.3
Chlorella, marine	10.1	35.1	4.2	5.6	27.7	27.4
Isochrysis galbana	10.4	33.6	18.1	4.4	23.0	20.9
Moina macrocopa	8.5	57.8	7.6	8.4	17.2	9.0
Sargassum	10.4	9.0	0.8	9.6	36.4	34.2
Skeletonema sp.	10.4	24.7	2.6	0.7	20.2	51.8
Spirulina	8.0	55.7	2.8	0.6	28.1	11.8

TABLE 16 CONTINUED

Natural food						
Tetraselmis sp.	5.5	49.1	10.7	2.1	19.0	19.1
Digman	9.8	20.6	3.3	16.4	35.9	23.8
Enteromorpha (lumot)	15.2	13.8	1.9	9.3	36.9	38.1
Gracilaria sp.	7.0	10.2	0.4	5.8	44.8	38.8
Kappaphycus sp.	6.1	5.4	0.8	6.1	57.3	30.4

** Nitrogen-free extract

Source: Catacutan (2002a); Eusebio, Coloso and Mamauag (2004); Millamena *et al*. (2000); Centralized Analytical Laboratory, SEAFDEC

bread and biscuit rejects and commercial poultry feeds are sometimes provided as supplemental feeds. Commercial feeds are only used in intensive tank culture, earthen ponds or floating cages. Commercial feeds for milkfish and tilapia contain high levels of plant material, such as rice bran, soybean meal and low levels of fishmeal (see Table 21). Catfish are also omnivorous but have a higher protein demand and they fed on decaying organic matter supplemented with kitchen waste, blanched chicken entrails and rice bran. Catfish cultured in net pens are fed a commercially formulated feed.

Carnivorous fish. Raw fish and chopped shrimp (*Acetes* sp.) is generally fed to carnivorous species such as grouper and red snapper in cages or pens. An alternative feeding strategy employed in brackish-water pond culture of grouper is to use tilapia fry as live food, together with chopped trash fish. To decrease the dependence on trash fish, formulated feeds have now also been developed for carnivorous marine species.

Herbivorous fish and plankton feeders. Herbivorous species like rabbitfish are grown in brackish-water ponds and fed on filamentous algae such as *Enteromorpha*.

Crustaceans. Shrimps cultured in extensive systems feed mostly on detritus, diatoms, *Cyanobacteria* and green algae. In semi-intensive systems shrimp are given commercial feeds (Table 21).

Mudcrabs. Raw fish and freshly ground mussel meat are typical feeds for mud crab in ponds or pens installed in tidal flats. If available, *Acetes*, green filamentous algae, animal hides and entrails and snails are also given to mud crabs. A mud crab diet has been developed but has not yet been commercialized. The formulation contains high levels of fishmeal and brown mussel meat (Table 21).

2.2 Feeding strategies and pond management

2.2.1 Milkfish

Pond culture. Culture practices for milkfish in brackish-water ponds range from extensive, modified extensive, semi-intensive to intensive. Most milkfish farmers use extensive and modified extensive farming practices. The practices differ with respect to stocking density, feeding strategy and water management (Table 22 and 23). Under extensive conditions, ponds are prepared to produce adequate quantities of natural food. Chicken manure is applied at 1–2 tonnes/ha, 16-20-0 at 50 kg/ha and 46-0-0 at 15 kg/ha. To maintain natural food productivity throughout the production cycle, inorganic fertilizers are applied after water exchanges that occur every 15 days at equal or half of the application rates applied for pond preparation. *Lab-lab* (bacterial/algal floc) and plankton are the two preferred natural feeds.

Feed is only provided in the last month of the cycle when natural food cannot sustain fish growth. Fertilization alone can only support fish biomass of around 600 kg/ha (Sumagaysay, Marquez and Chiu-Chern, 1991). A small number of fish farmers practice the 'kitchen pond method', which entails growing and transferring of natural food from a small pond (kitchen pond) to rearing ponds. Polyculture of milkfish with shrimp is also practised in extensive systems, with or without supplemental feeding.

Under semi-intensive conditions, ponds are prepared and fertilized as above. Feeding with commercial feeds commences one month after stocking. Water exchange is more frequent and for which a pump is normally required. Aeration is employed when biomass reaches 1 tonne/ha. Milkfish in ponds was reportedly to effectively use only about 12 percent of the feed provided (Luckstädt, 2003). Rice bran may therefore not directly contribute to fish growth but plays an important role in natural food production.

Marine pen and cage culture. The stocking density of milkfish in pens is between 5–20 fish/m^2. For floating and stationary cages, total biomass is between 10–30 fish/m^3. In offshore cages, stocking density is increased to 35–100 fish/m^3 and fish are given commercial feeds. The average FCR in pens and cages is 2.5:1 and this needs further improvement. Pen culture of milkfish is also practiced in lakes, particularly in Laguna de Bay where some 12 000 ha are used for pen culture (Santiago, 2001; Filart, 2005).

The feeding scheme for grow-out culture of milkfish in shown in Figure 5.

With the high demand for milkfish fry, hatcheries have been established all over the country and feeding protocols are well established (Borlongan, Marte and Nocillado, 2000).

TABLE 17

Apparent protein digestibility coefficients (APDC) of feedstuffs by Philippine aquaculture species

Species	Feedstuffs	APDC (%)
Milkfish	Fishmeal	45–81*
	Soybean meal, defatted	45–94*
Tiger shrimp	Fishmeal	61
	Soybean meal, defatted	93
	Squid meal	96
	Shrimp meal	95
	Shrimp head meal	89
	Meat and bone meal	74
	Yeast, *Candida* sp.	93
	Copra meal	75
Carp	White fishmeal, mechanically extracted	95
	Soybean meal, solvent extracted	81–96
Grouper	Fishmeal, Chilean	98
	Fishmeal, white	99
	Fishmeal, tuna	76
	Shrimp meal, *Acetes* sp.	95
	Squid meal	94
	Soy protein	86
	Meat soluble	98
	Meat and bone meal, Philippines	84
	Meat and bone meal, Australia	99
	Poultry feather meal	81
	Blood meal	15
	Rice bran	43
	Wheat flour	83
	Cowpea meal, white	94
	Lupin seed meal	97
	Corn gluten meal	99
	Corn germ meal	83
	Leucaena leaf meal	79
Mud crab	Fishmeal, Peruvian	95
	Squid meal	98
	Shrimp meal, *Acetes* sp.	95
	Meat and bone meal	95
	Copra meal	94
	Bread flour	95
	Rice bran	94
	Corn meal	96
	Soybean meal, defatted	96

* Tested at different salinities (Ferraris *et al*., 1986)

Source: Milkfish - Ferraris *et al.* (1986); tiger shrimp – Catacutan (1997); carp – NRC (1977); grouper – Eusebio, Coloso and Mamauag (2004); mudcrab – Catacutan, Eusebio and Teshima (2003)

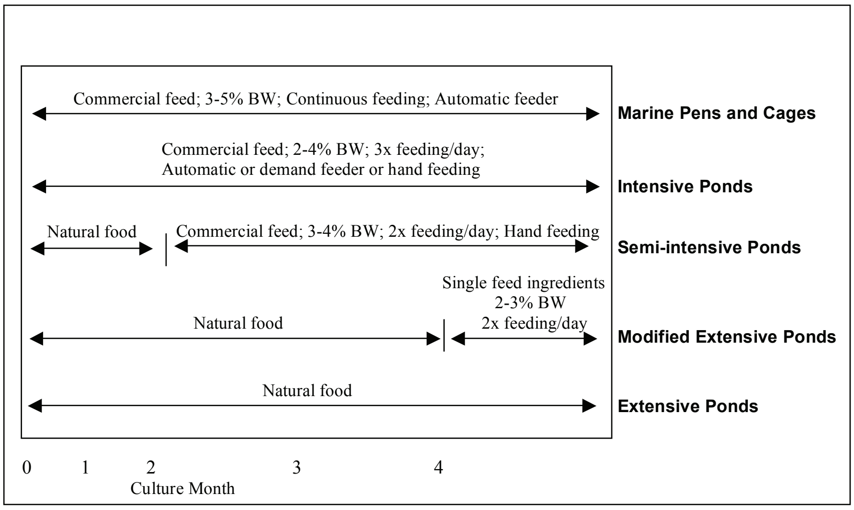
2.2.2 Tilapia

Tilapias in the Philippines are reared in cages, tanks and ponds under mono- or polyculture conditions with other fish. Culture techniques may be extensive, semi-intensive or intensive and these differences are summarized in Table 23.

Cage culture. Tilapia cage culture is well established in Luzon and Mindanao. The proliferation of fish cages in most lakes has severely depleted natural food resources and has forced farmers to rely on commercial pellets. Sinking or floating commercial pellets are used as feed and fish are fed to satiation two to three times a day. FCRs vary widely (1.8–3:1) and are affected by water quality. Feeds are either broadcast or applied on feeding trays. Aeration is also employed in lakes regardless of biomass or fish size.

Pond culture. The management of tilapia in ponds is similar to milkfish. *Lab-lab* and plankton are grown in extensive and semi-intensive systems. In addition, sacks of fertilizer are suspended in the water column (Aldon, 1998). Chicken manure or hog manure is applied at 500–1 000 kg/ha per week, while inorganic fertilizers, 16-20-0 or

FIGURE 5
Feed management protocols for milkfish grow-out in different systems



Source: FPA (unpublished report)

TABLE 18
Nutritional requirements of some species cultured in the Philippines

Species	Crude protein (%)	Crude lipid (%)	Carbohydrate (%)	Digestible energy (kcal/kg)
Milkfish	30–40[1]/24 (pond)[2]	7–10[11]	25[14]	2 500–3 500[17]
Nile tilapia	28–30[3]	6–10[12]	25[15]	2 500–4 300[18]
Tiger shrimp	40[4]	8–12[13]	20[16]	2 850–3 700[19]
White shrimp	28–32[5]	-	-	-
Mud crab	32–40[6]	-	-	-
Common carp	31–38[7]	-	-	-
Grouper	40–50[8]	-	-	-
Asian seabass	43[9]			-
Red snapper	44[10]	-	-	-
Species	**Essential fatty acid (%)**	**Lecithin (%)**	**Cholesterol (%)**	
Milkfish	1–1.5 n-3 PUFA[20]	-	-	
Nile tilapia	0.5 18:2n-6 PUFA[21]	-	-	
Tiger shrimp	2.6 n-3 PUFA[22]	1-2[25]	1[26]	
	<5 n-6 PUFA			
Grouper	1 n-3 HUFA[23]	-	-	
Asian seabass	0.5 n-3 PUFA[24]	-	-	
	0.5 n-6 PUFA			

Source: [1]Lim, Suchawongs and Pascual (1979); [1, 11,14,17]Pascual (1989a); [2]Sumagaysay and Borlongan (1995); [3]Santiago *et al.* (1986); [3]Wang, Takeuchi and Watanabe (1985); [4]Alava and Lim (1983); [4]Millamena and Triño (1994); [5]Sedgewick (1979); [6]Catacutan (2002b); [7]Takeuchi, Watanabe and Ogino (1979); [8]Teng, Chua and Lim (1978); [9]Catacutan and Coloso (1994); [10]Catacutan, Pagador and Teshima (2001); [12,15,18]Jauncey and Ross (1982); [13,22]Catacutan (1991); [16,19]Bautista (1986); [20]Borlongan (1992); [21]Takeuchi, Satoh and Watanabe (1983); [23]Millamena and Golez (1998); [24]Borlongan and Parazo (1991); [25]Pascual (1989b); [26]Nalzaro (1982)

18-46-0 are applied at 25–50 kg/ha every two weeks. In intensive systems commercial feeds are broadcast at several sites. Water is exchanged frequently.

Concrete tank culture. Production levels of up to 86 tonnes/ha/year can be achieved under intensive tank culture conditions. However, operational costs are high and maintenance of water quality is critical (Aldon, 1998).

2.2.3 Catfish

The native catfish, *Clarias macrocephalus,* has disappeared from the Philippine market due to pesticide poisoning, loss of habitat and overfishing. Walking catfish *C. batrachus* was introduced in the early 1980's but was not readily accepted by

TABLE 19
Vitamin requirements of some important species cultured in the Philippines (values in mg/kg diet unless otherwise indicated)

Vitamins	Tilapia	Tiger shrimp	Common carp	Seabass	North African catfish
Thiamine		60			
Riboflavin		25	7–14		
Pyridoxine			5–6		
Cobalamin		0.2			
Pantothenic acid		75 or 101–139	30–50		
Nicotonicacid		40	28		
Biotin		2.0–2.4	1		
Inositol		400	440		
Choline		600	4000		
Folic acid		10			
Ascorbic acid		200		700	0.1–0.7 g ASA/100 g for wound healing
Vitamin A		5 000 IU	10 000 IU		
Vitamin E	50–100	100	1 000 IU		
Vitamin D		0.1			
Vitamin K		5			

Source: Erazo-Pagador (2001); Millamena (2002); Shiau and Chin (1998); Shiau and Hsu (1998)

TABLE 20
Mineral requirements of some species cultured in the Philippines

Minerals	Nile tilapia	Tiger shrimp	Common carp	Milkfish
Ca		1:1 (Ca:P)		
P	0.8–-1.0%		0.6–-0.7%	0.85
Mg	0.05–-0.07%		0.04–-0.05%	
Cu	3–-4 ug/g			
Fe			150 ug/g	
Mn	12 ug/g		13 ug/g	
Zn	10 ug/g		15–-30 ug/g	

Source: Borlongan and Satoh (2001); Watanabe, Satoh and Takeuchi (1988); Bautista and Baticados, (1990); Millamena (2002)

consumers. The introduction of the North African catfish, *Clarias gariepinus*, in the early 1990's, has helped to revive the catfish culture industry. Catfish are cultured in freshwater ponds or in cages (Surtida and Buendia, 2000). A formulated feed for catfish grow-out is available (Table 21). Smaller catfish farms use ponds of around 1 000 m^2 at a stocking density of 5–6/m^2 and use the water from the ponds to grow vegetables. In these systems, swine pellets are fed twice daily at 1–3 percent of body weight per day. Semi-intensive catfish farmers use ponds of up to 5000m^2, stock their ponds at 10/m^2 and feed the fish on trash fish, processed chicken entrails or swine pellets and change water twice weekly.

2.2.4 Grouper

Grouper culture in the Philippines is still dependent on the use of fry and juveniles caught from the wild or produced from the hatchery. Fish are reared either in ponds or in cages (Baliao *et al*., 1998; Baliao *et al*., 2000). Detailed feeding and water management protocols for larval and early juvenile grouper are described by Duray, Estudillo and Alpasan (1997).

Pond culture. Pond preparation procedures for growing natural food (*lab-lab* and plankton) are similar to milkfish culture. Adult tilapia are stocked in the ponds at 5 000–10 000 fish/ha to breed and the fry and early juveniles serve as prey for the grouper. Juvenile grouper are stocked at 5 000 fish/ha, one month after the release of the adult tilapia. Trash fish is also provided at 5 percent of biomass per day. If trash fish is the only feed then the ration is increased to 10 percent of biomass per day. Water is changed twice weekly. A formulated feed for grouper is now available (Table 21).

Cage culture. Net cages are installed in sheltered lagoons, coves, bays, behind an island or in river mouths. For the nursery phase the fish are stocked at 10–20/m^3. Feeds include mysids, shrimps or finely chopped trash fish at a ration of 10 percent body weight per

TABLE 21
Practical diet formulation for milkfish, tilapia, waliking catfish, grouper, mud crab and tiger shrimp (g/kg as fed basis)

Ingredient composition	Milkfish[1]	Tilapia[2]	Catfish[3]	Grouper[4]	Mud crab[5]	Shrimp[6]
Fishmeal (local)		182.5	200	-	-	
Chilean/Peruvian fishmeal	110	-	-	200	250	250
Meat and bone meal				200		
Brown mussel meat	-	-	-		250	
Blood meal				80		
Squid meal	-	-	-	10	-	
Shrimp meal (*Acetes* sp.)	-	-	-	100	-	150
Soybean meal	308	250	300	60	-	250
Copra meal	-	100			-	
Rice bran	492	60	310	70	125	69.5
Corn bran	-	-	-		100	
Cassava flour	-	364.2	-		-	
Bread flour	50	-	90		-	130
Wheat flour	-	-	-	150	170	
Seaweed (*Gracilaria* sp.)	-	-	-		50	50
Cod liver oil	20	-	-	60	25	25
Soybean oil	20	-	50		25	25
Vitamin mix	-	-	-	40	-	20
Mineral mix	-	-	10	30	-	10
Vitamin-mineral mix	-	43.3	10		-	
Dicalcium phosphate	-	-	30		-	20
Ethoxyquin	-	-	-		5	0.5
Proximate composition (% dry matter)						
Crude protein	26.7	28.1	34.2	44.0	40.1	41.7
Crude lipid	10.9	3.8	9.5	11.5	11.9	8.8
Crude fibre	8.4	3.6	5.8	1.8	1.4	5.9
Nitrogen-free extract	45.1	54.6	36.3	25.8	38	29.2
Ash	8.9	9.9	14.2	16.9	8.6	14.4
Cost (US $/tonnes)**	**375**	**559**	**402**	**1 300**	**781**	**806**

*Cost of feed calculated based on average retail cost of ingredients

Source: [1]Sumagaysay (1998); [2]Santiago, Aldaba and Reyes (1987); [3]Coniza, Catacutan and Tan-Fermin (2001); [4]Millamena *et al.* (2001) in Alava (2002); [5]Triño, Millamena and Keenan (2001); [6]Millamena and Triño (1994)

day, fed twice a day. A 50 Watt incandescent bulb is sometimes installed above the cages to attract live food (mysids, copepods and other juvenile fish). In grow-out cages, chopped trash fish is provided twice daily at 5 percent of body weight per day.

2.2.5 Mudcrab

Mudcrab are farmed in bamboo fenced brackish-water ponds. Net enclosures are installed along the inner side of the pond dykes to prevent escape. Prior to stocking, the pond is prepared by liming, application of 21-0-0 and organic and inorganic fertilizers. In polyculture with milkfish the ponds are modified to suit the needs of the two species. Peripheral and central canals are constructed where crabs can seek refuge in deeper water when temperature rises above 32° C, while lab-lab as food for milkfish can still grow in the shallow parts of the pond. Mudcrab are also reared in mangrove areas or on tidal flats in net pens (1–2 cm mesh size). Stocking density less than 5 000 crabs/ha is recommended to attain bigger size and higher survival.

Crabs are fed on fresh or frozen trash fish or in combination with brown mussel meat (75 percent brown mussel and 25 percent trash fish). Animal hides or entrails, snails, *Acetes* and green filamentous algae are also used as feed. Crabs are fed at 10 percent of body weight when carapace length is less than 6 cm and at 5 percent when carapace length is 6 cm or more. A dry formulated feed (Table 21) is also used at 5 percent of biomass daily when carapace length is ≤ 6 cm and at 2 percent of biomass when carapace length is ≥ 6 cm (Alava, 2002).

TABLE 22
Different milkfish culture systems in brackish water

Culture System	Optimum stocking density/ha	Yield (kg/ha/crop)	Food supply management	Water management
Extensive polyculture				
Milkfish	3 000–3 500	600–800	Natural food +	Tidal
Shrimp	5 000–10 000	120–240	supplemental feed	
Extensive monoculture				
Traditional	1 000–2 000	500–600	Natural food + freshwater filamentous algae	Tidal; water depth, 60 cm or less
Improved	2 000–3 000	700–1 000	*Lab-lab* (high salinity)	Water depth, 50 cm or less
Modified extensive monoculture				
Modified stright-run	4 000	1 000	Mainly natural food + supplemental feed	Tidal; water depth 80 cm
Modular	3 000	2 000	Natural food (*lab-lab* and plankton)	Tidal
Semi-intensive polyculture				
Milkfish	10 000	2 250	Natural food + supplemental or commercial feed	Tidal: supplemental pumping
Shrimp	35 000	840		
Semi-intensive monoculture				
	8 000–15 000	1 500–3 500	Natural food + supplemental or commercial feed	Tidal: supplemental pumping; water depth, 50-100cm
Intensive				
	≥20 000	≥4 000	Commercial feed	Pumping with aeration; water depth, 12 cm

Source: Bagarinao (1997); Sumagaysay-Chavoso (2003); author's survey (2005)

TABLE 23
Tilapia culture systems in the Philippines

Parameters	Extensive	Semi-intensive		Intensive		
	Ponds	Cages	Ponds	Cages	Ponds	Tanks
Culture period	4–5 months	4–6 months	4–6 months	4–5 months	4–5 months	4–5 months
Size at stocking	10–20 g	10–20 g	10–20 g	10–20 g	10–20 g	10–20 g
Stocking density	3 000–5 000/ha	15–25/m^3	10 000–50 000/ha	50–250/m^3	50 000–100 000/ha	100–200/m^3
Water management	50% water change after 2 months	None	Frequent water change	None	5–10% daily	Flow-through
Fertilization	2 weeks after pond preparation	None	Applied in first two months	None	Only at stocking	None
Feeding	None	Natural food + supplemental feed	Natural food + supplemental feed	Commercial feed	Commercial feed	Commercial feed
Use of aerator	No	No	Optional	Optional	Yes	Yes
Size at harvest	100–200 g	250–300 g	150–200 g	150–250 g	250 g	>300 g
Survival rate	80–100%	70–90%	60–85%	60%	60%	70–85%
Yield	300–800 kg/ha	2.7–7.0 kg/m^3	1 000–3 000 kg/ha	4–40 kg/m^3	7 000–15 000 kg/ha	20–50 kg/m^3

Source: Guerrero (2002); Aldon (1998); Corpuz-Uy (pers. com.); author's survey (2005)

2.2.6 Tiger shrimp

Broodstock conditioning. Broodstock shrimp are fed with a variety of live, fresh or frozen marine worms, mussel meat, squid, clam meat and other mollusc meat. Brown mussel meat and squid are chopped into small pieces, while marine worms are fed alive. A formulated feed is also used but is supplemented with fresh wet feeds to ensure nutrient balance (Alava, 2002). Broodstock tanks are operated on a flow through basis or water is changed daily.

Larval rearing. The protocols described by Bautista, *et al.*, (1991) are generally used for larval and PL rearing up to PL_5. From PL_6 onwards, postlarvae are gradually introduced to minced mussel meat, raw fish and shrimp meal or crumbled artificial feed. Shrimp larval diets are readily available and are easy to use (Alava, 2002).

Grow-out culture in ponds. Extensive shrimp farming at densities of 30 000-50 000 shrimp/ha can attain production of 0.8-1.1 tonnes/ha/crop (Bordeos, 2004). Pond preparation involves sun drying of pond bottom, excavation of peripheral canals, scraping of black soil, liming, and application of tea seed powder as pesticide. Algal growth is stimulated by seeding green water from the river or adjacent ponds and by fertilization. These techniques were developed to prevent occurrence of diseases and to remove organic matter from the pond bottom. Feeding with commercial feed commences 5 days after stocking until harvest. Stocking density in semi-intensive and intensive systems is recommended not to exceed 250 000/ha for sustainability (Corre *et al*., 1999). Like in extensive system, farmers follow the feeding scheme suggested by feed manufacturers or developed their own.

3. THE AQUACULTURE FEED INDUSTRY

Fifteen years ago, pelleted animal feeds in the Philippines were rarely available and used (Solalela, 2001). Today, approximately 80 percent of animal feeds are in pellet or crumble form. Mash is used as a poultry feed and by cost conscious fish farmers. The animal feed industry (including aquafeeds) is now sophisticated and well established and all types of feeds are available, either produced locally or imported.

3.1 Cost of raw materials and feeds

Raw material comprises approximately 85 percent of the feed production cost, hence is considered as the primary concern by feed manufacturers. The balance of 15 percent covers all other production costs including amortization (Solalela, 2001). The cost of feed ingredients varies widely depending on quality, source and time of purchase (Table 24). For various reasons the cost of animal feeds is higher in the Philippines than many other countries (Solalela, 2001). The country is highly dependent on imported fishmeal, corn and soybean meal and this is compounded by the poor quality of locally produced corn, fishmeal and rice bran. The supply of corn in the country is regulated and monitored by the NFA (AFSD-BAI, 2005).

3.2 Available aquafeeds

Over 60 brands of milkfish feeds, 65 tilapia feeds and 9 shrimp feeds where available on the market in December 2004. The cost of feed depends on the nutrient composition, quality, manufacturing process and competition between milling companies and distributors. Average prices of the available aquafeeds are presented in Table 24. Generally, fish feeds are available in mash form for fry (pre-starter), crumble (starter) for small juveniles and pellets (grower and finisher) for later stages. The protein content of the available commercial feeds for different species are: milkfish, 35–26 percent (fry to 500 g weight); tilapia, 31–23 percent (0.01 g fry to 1000 g); catfish, 34–29 percent (<5 g fry to >80 g); grouper, 48–42 percent (<2 g fry to >300 g); shrimp, 45–37 percent (<1 g post-larvae to >15 g). All of the reputable manufacturers provide a guaranteed composition of their various feed and also provide farmers with a feeding guides for each feed type. Three examples of feed composition and feeding schedules are provided in Tables 25 (a-f). These data exist for all species specific feeds. Specific formulations are also available for different culture systems and conditions. The survey revealed that floating/extruded pellets are between 6–25 percent (average = 14 percent) more expensive than sinking pellets with similar nutrient composition.

Feed companies are required to register with the Bureau of Animal Industry (BAI) and comply with feed standard regulations (Table 26). The government sets nutrient standards for different species according to feeding habits and life stages, though discrepancies between the standards and the nutrient specifications provided by manufacturers do sometimes exist.

3.3 Marketing of aquafeeds

Aquafeeds (except in mash form) are usually sold in standard 25-kg polypropylene bags. These are distributed and sold together with livestock and poultry feeds by agricultural supply stores. The marketing chain for aquafeeds is well organized and begins with the manufacturer who distributes products either to a wholesaler or to an authorized area distributor. Wholesalers sell to dealers who have their own set of retailers for final distribution to end-users. Authorized dealers sell directly to farmers. Some major feed companies have their own distribution warehouses in key areas. In such cases, the company deals directly with large customers. Feed manufacturers provide sales incentives to wholesalers and/or dealers depending on the volume of their total sales. Technical and sales agents provide technical services and promotional activities to boost feed sales. Promotions are done through sponsorship of community and industry activities (*e.g.* exhibits, seminars), feed trials and distribution of promotional items (ADB, 2002 study).

TABLE 24
Approximate cost of selected ingredients and aquafeeds

Ingredient	Cost (US$/tonnes)
Fishmeal, Peruvian	855–1 000
Fishmeal, local (sardine, tuna, various species)	236–536
Prawn head meal	300
Squid meal	11 212
Soybean meal	345–527
Copra meal/cake	58–236
Rice bran	55–175
Wheat (whole)	148–218
Bread flour	444
Corn starch	409
Corn bran	58
Soybean oil	727
Cod liver oil	2 273
Fish oil	509
Crude coconut oil	600–618
Used oil from fast foods	444
Vitamins/minerals	2 182–8 335
Dicalcium phosphate	509
Species/feed type	
Milkfish	
Mash	431–1051
Starter crumble	417–464
Starter pellet	407–445
Grower/juvenile	379–465
Finisher/adult	373–455
Shrimp	
Pre starter crumble	1 298
Starter pellet	931–1 022
Grower	895–967
Finisher	876–931
Catfish	
Starter	432
Grower	407
Finisher	400
Grouper	
Fry mash	949
Crumble	958
Starter	912
Grower	876
Finisher	849
Tilapia	
Mash	469
Starter crumble	458
Starter pellet	451
Grower/juvenile	429
Finisher/adult	418

Source: Feed distributors and manufacturers

3.4 Status of commercial feedmills

Capacity and production. The total rated capacity of all registered commercial animal feedmills is approximately 23 470 tonnes per eight-hour shift, of which the 78 aquafeed milling companies have a capacity of 10 451 tonnes per eight-hour shift (Table 27). Approximately 61.8 percent of all registered manufacturers are small-scale producers with a rated capacity of less than 25 tonnes per 8-hr shift, while 25.6 percent are large-scale producers with a capacity of 50 tonnes or more per 8-hr shift. The large-scale millers manufacture approximately 80 percent of the total animal feed produced in the country. To improve efficiency and to save costs feedmillers have formed several industry associations, of which the Philippine Association of Feedmillers, Inc. is at the forefront.

Total animal feed production (including aquafeeds) in 2003 was 2.6 million tonnes, of which 8 percent (204 396 tonnes) comprised aquafeeds (Table 28). Shrimp feed production declined from 50 000 tonnes in the late 1980s to 11 472 tonnes in 2003. The growth of finfish aquaculture has contributed to the expansion of the aquafeed industry. Fish feeds now comprise between 94–96 percent of all aquafeeds. Aquafeed production increased by an average of 10 percent per annum from 1996-2003 (Solalela 2001). The overall production capacity of aquaculture feedmills based on the 8-hr rated

TABLE 25A

Guaranteed analysis of several commercial milkfish feeds

Feed type	Crude protein % (min)	Crude lipid % (min)	Crude fibre % (max)	Ash % (max)	Moisture % (max)
B-MEG Bangus					
Fry mash	31	8	7	16	13
Starter crumble	31	8	7	16	13
Starter pellet	31	8	7	16	13
Grower pellet	31	8	7	16	13
Finisher pellet	29	8	7	16	13
HP Premium Bangus Feeds					
Fry mash	32–35	7	4	12	12
Starter crumble	30	7	4	12	12
Starter pellet	30	7	4	12	12
Juvenile	28	7	4	12	12
Adult	26	7	4	12	12
HP Regular Bangus Feeds					
Juvenile	27	6	5	11	12
Adult	25	6	5	11	12

TABLE 25B

Recommended feeding schedules for milkfish provided by feed manufacturers

Feed type	Average body weight (g)	Feeding rate (% BW/day)	Growth rate (g/day)	Feeding frequency (x/day)	Feeding duration (days)
B-MEG Bangus					
Fry mash	0.01–2.00	12.5–20.0	0.15±0.02	-	-
Starter crumble	2.1–25.0	7.2–10.0	0.77±0.12	-	-
Starter pellet	26.0–70.0	5.1–6.9	2.30±0.34	-	-
Grower pellet	71.0–170	3.5–4.8	2.90±0.58	-	-
Finisher pellet	171.0 and above	1.5–3.2	3.20±0.80	-	-
HP Premium and Regular Bangus Feed					
Fry mash	fry - 15	8.5–10.0	-	5	30
Starter crumble	15–30	5–7	-	4	20
Starter pellet	30–100	4.0–4.5	-	4	45
Juvenile 2.4[a]	100–200	3–4	-	3	30
Juvenile 3.0[a]	200–-400	2.8–3.0	-	3	30
Adult 2.4 & 3.0	400–-500	2.5–3	-	3	30

[a]Number refers to pellet diameter

Source: San Miguel Foods, Inc (B-MEG); Hoc Po Feeds Corp (HP)

TABLE 25C

Guaranteed analysis of various commercial tilapia feeds

Feed type	Crude protein % (min)	Crude lipid % (min)	Crude fibre % (max)	Ash % (max)	Moisture % (max)
B-MEG Tilapia					
Fry mash	30	8	7	16	13
Starter crumble	30	8	7	16	13
Starter pellet	30	8	7	16	13
Grower pellet	30	8	7	16	13
Finisher pellet	28	8	7	16	13
Vitarich					
Premium					
Fry mash	≥31	≥4	≤8	-	≤13
Fry crumble	≥31	≥4	≤8	-	≤13
Extruded juvenile pellet	≥28	≥8	≤10	-	≤13
Extruded adult pellet	≥27	≥8	≤10	-	≤13
Extruded adult pellet with molasses	≥27	≥8	≤10	-	≤13
Extru-edge aqua float juvenile[a]	≥30	≥4	≤8	-	≤13
Extru-edge aqua float adult[a]	≥28	≥4	≤8	-	≤13
E-qual					
Extruded juvenile pellet	≥24	≥6	≤8	-	≤10
Extruded adult pellet	≥24	≥6	≤8	-	≤10
Extru-edge juvenile float[a]	≥25	≥4	≤8	-	≤13
Extru-edge adult float[a]	≥23	≥4	≤8	-	≤13

[a]Refers to extruded floating pellet

TABLE 25D

Recommended feeding schedules for tilapia provided by feed manufacturers

Feed type	Average body weight (g)	Feeding rate (% BW/day)	Growth rate (g/day)	Feeding duration (weeks)
B-MEG Tilapia				
Fry mash	0.01–2.00	15–20	0.02±0.01	-
Starter crumble	2–15	7–10	0.35±0.05	-
Starter pellet	16–37	5.9–7.0	0.47±0.07	-
Grower pellet	38–83	4.4–5.8	0.86±0.20	-
Finisher pellet	91–1 000	1.5–4.1	1.8±0.40	-
Vitarich				
Fry mash	3–15	6–13	-	1–3
Fry crumble	2262	5–6	-	4–7
Extru-edge aqua float juvenile[a]	62–130	3–5	-	7–10
Extruded juvenile pellet	77–105	3–4	-	8–9
Extruded adult pellet	130–250	2–3	-	10–14
Extru-edge aqua float adult[a]	160–250	2.0–2.5	-	11–14
Extruded adult pellet with molasses	16–250	2.0–2.5	-	11–14

[a]Refers to extruded floating pellet

Source: San Miguel Foods, Inc (B-MEG); Vitarich Corp. (Vitarich)

TABLE 25E

Guaranteed analysis of various commercial shrimp feeds

Feed type	Crude protein % (min)	Crude lipid % (min)	Crude fibre % (max)	Ash % (max)	Moisture % (max)
B-MEG CE 90					
Pre-starter/PL	38.5	4.0	2.5	13	10
Starter	38.0	4.0	3.0	13	10
Grower	37.0	4.0	3.0	14	10
Finisher	37.0	3.5	4.0	15	10
Tateh Shrimp Feed					
Pre-starter (mash)	45.0	8.0	4.0	16	12
Pre-starter (crumble)	45.0	8.0	4.0	16	12
Starter (pellet)	42.0	6.0	4.0	16	12
Grower (pellet)	40.0	6.0	4.0	17	12
Finisher (pellet)	38.0	6.0	4.0	17	12

TABLE 25F

Recommended feeding guide for shrimp provided by feed manufacturers

Feed typ	Average body weight (g)	Feeding rate (% BW/day)	Feed distribution per feeding (%)					Tray allocation (%)[a]
			6 am	10 am	2 pm	6 pm	10 pm	
B-MEG CE-90								
PL/Pre-starter	PL15-DOC14[b]		30	-	-	35	35	-
Starter	DOC15-DOC21	6.0–4.0	20	20	-	30	30	2.4[a]
Starter	DOC22-DOC30	3.7–-3.4	20	15	15	30	20	2.7
Starter	2.0–5.0	3.7–-3.4	20	15	15	30	20	2.7
Grower	6.0–8.0	3.7–3.4	20	15	15	30	20	2.7
Grower	9.0–12.0	3.2–3.0	20	15	15	30	20	3
Grower/finisher	13.0–19.0	2.9–2.6	20	15	15	30	20	3.3
Finisher	20.0–28.0	2.6–2.4	20	15	15	30	20	3.6
Finisher	29.0–34.0	2.4–2.3	20	15	15	30	20	3.9
Finisher	35.0–60.0[£]	2.3–1.8	20	15	15	30	20	4.1–4.9
Tateh Shrimp Feed								
Pre-starter (mash, crumble)	<1.5	blind feeding[c]	30	-	-	40	30	none
Pre-sStarter (crumble)	1.5–5.0	9.0–6.5	25	15	-	30	30	1
Starter (pellet)	5–10	7.0–5.5	25	10	10	25	30	1
Grower (pellet)	10–15	6.0–4.5	25	10	10	25	30	1
Grower (pellet)	15–20	5.0–3.5	25	10	10	25	30	1
Grower (pellet)	20–25	4.0–3.0	25	10	10	25	30	1
Finisher (pellet)	25–30	3.5–2.5	25	10	10	25	30	1
Finisher (pellet)	30–35	3.0–2.0	25	10	10	25	30	1
Finisher (pellet)	35 and up	2.5–1.5	25	10	10	25	30	1

[a]Percentage of feed ration placed in feeding trays; [b]DOC – days of culture; [c]Feed is given at fixed ration of 1-2 kg/100 000 shrimps

Source: San Miguel Foods, Inc (B-MEG); Santeh Feeds Corp. (Tateh)

TABLE 26
National nutrient standard for aquaculture feeds

Type of feed	Crude protein % (min)	Crude lipid % (min)	Crude fibre % (max)	Moisture % (max)	Ash % (max)
Prawn					
Pre-starter, pellet/crumble	38	4	4	12	16
Starter, pellet/crumble	37	4	4	12	16
Grower, pellet/crumble	35	4	4	12	17
Finisher, pellet/crumble	30	4	5	12	17
Omnivore fishes					
Pre-start mash, pellet/crumble	35	4	4	12	15
Starter mash, pellet/crumble	29	4	6	12	15
Grower mash, pellet/crumble	27	4	9	12	16
Finisher mash, pellet/crumble	35	4	9	12	16
Carnivore fishes					
Pre-start mash, pellet/crumble	45	4	4	12	15
Starter mash, pellet/crumble	40	4	6	12	15
Grower mash, pellet/crumble	35	4	9	12	16
Finisher mash, pellet/crumble	30	4	9	12	16

Source: Department of Agriculture (1996)

TABLE 27
Distribution of commercial feed millers in the Philippines and production capacity of feedmills in tonnes per 8-hour shift

Region	Total registered feed mills		Registered aquafeed mills	
	No.	Total rated capacity	No.	Total rated capacity
NCR	53	4 665	11	3 034
I	9	1 496	3	885
II	8	938	0	0
III	115	8 051	28	4 247
IV	93	4 037	15	1 271
V	14	505	0	0
VI	13	469	6	272
VII	32	1 461	9	295
VIII	3	110	0	0
IX	6	96	0	0
X	11	533	1	10
XI	14	488	1	108
XII	21	613	3	326
XIII	3	8	1	3
Total	**395**	**23 470**	**78**	**10 451**

Source: AFSD-BAI (2005)

capacity is 3.8 million tonnes/year. Given the estimated production of 204 396 tonnes of aquafeed in 2003 suggests that only 5.4 percent of the installed capacity is effectively used. Never the less, in recent years the aquafeed industry has improved enormously in manufacturing processes, quality control, feed formulation and in keeping costs as low as possible.

Distribution and storage capacity. The national distribution of feedmillers is presented in Table 27. Luzon (including NCR, Region III, Region IV) contributes 90.3 percent (3 444 505 tonnes/year) to total animal feed production in the country. The demand for compounded and or mixed animal feeds is regionally unequal and the concentration of feedmill capacity in Luzon has had negative impact on marketing, distribution and feed cost.

Because of the seasonal nature of domestic raw material supply millers have found it more economical to channel the procurement of raw materials to dealers and thus, free themselves of maintaining large year-round storage facilities. However, the shortage and rising prices of raw materials in recent years has forced the industry to expand its storage facilities (AFSD-BAI, 2005). Some companies forward buy in expectation of low supply and high price. There seems to be no problem with the storage capacity to warehouse the finished products.

3.5 Consumption of aquafeeds

Of the 204 396 tonnes of aquafeed produced, 144 356 tonnes were unspecified feeds (AFSD-BAI, 2003) (see Table 30). Based on several assumptions, it was possible to calculate a breakdown of the consumption of domestically produced aquafeeds by species groups (Table 28).

From these data it is clear that the aquafeed industry only provides a fraction of the total feed requirements of the aquaculture industry in the Philippines. The difference is made up by the use of single ingredient feeds such as rice bran, trash fish, other farm-made feeds and imports (Table 12) of manufactured feeds.

TABLE 28
Consumption of domestically produced commercial aquafeeds by major species groups

Feed	Quantity (tonnes)	Actual or calculated
Total aquafeed production	**204 396**	**Actual**
Shrimp feed	11 472	Actual
Catfish feed	1 685	Actual
Tilapia feed	96 066	Calculated
Total milkfish feed	95 173	Calculated
Milkfish in cages and pens	54 543	Calculated
Milkfish and other species in ponds (e.g. grouper)	40 630	Calculated

Assumptions:
Tilapia feed = 47% of total aquafeeds (ADB, 2002)
Shrimp = 5.6% of total aquaculture feed
Catfish = 0.8% of total aquaculture feed
Total Milkfish (Total feed – Tilapia feed – Shrimp feed – Catfish feed) = 46.6%
Milkfish in cages and pens (production in 2003 at FCR = 2.5:1)

3.6 Economics of feeding

The cost of production varies with the level of intensification. The cost of production is lowest in extensive system (US$0.47/kg) and highest in intensive systems (US$0.84/kg) and this is related to high feed inputs and installation of life support systems (Table 29). Profits can still be made intensive milkfish culture as long as the higher production costs are compensated for by high yields and a high fish price. However, if the cost of fish is low then extensive systems, without feeding, are more profitable. This implies that farming practices may change periodically (e.g. extensive to semi-intensive, feeding to no feeding) to maximise income and profits depending on environmental factors (e.g., season, natural food production) and fish price (affected by supply and demand and price of other commodities).

4. PROBLEMS AND CONSTRAINTS

The increasing cost of raw material is the main problem that impacts on aquaculture and its associated feed industry. Because of the high cost of raw materials the Philippines is currently uncompetitive with respect to fish and shrimp production.

Availability of feed ingredients. The perennial shortage of key raw materials, such as fishmeal and soybean meal is highly problematic to feed manufacturers and feedmills that are unable to cope with the problem are forced to shutdown (AFSD-BAI, 2005). However, procurement is a greater problem for the smaller rather than the larger manufacturers in that they are better able to benefit from the National Food Authority procurement system, because of their bulk purchasing power. Clearly, there is a need for the smaller producers to cooperate such that they can also benefit from the NFA system.

High cost of feed. Feed prices are highly dependent on availability of local ingredients (rice bran, copra) and the cost of imported materials (especially fishmeal). Depreciation of the Philippine peso against foreign currencies has increased the domestic cost of imported ingredients. For example, the average cost of producing tilapia feed in 2003 was US$236–309/tonne, of which 70–90 percent of the cost was attributed to imported feed ingredients such as fishmeal, wheat, soybean meal, vitamins and minerals. The price of local ingredients is also volatile because of the seasonal nature of supply.

Low price of fish and a reduced demand for feed. The price of fish is largely dictated by the price of other market commodities and not necessarily related to the cost of production. Aquaculture products must compete with other meat and food. Intensive farmers are sometimes pressured to accept low prices due to large volume that have to be sold at harvest. If the profit margins are too low then farmers are discouraged to use feed and may revert to the more traditional culture methods. The effect of this is drop in the demand for manufactured feeds.

TABLE 29
Comparison of production costs (US$) under different culture conditions

Inputs	Culture Systems		
	Extensive	Semi-intensive	Intensive
Cost (US$/ha)			
Fertilizer	185.84	83.83	3.36
Feed	-	1 134.00	3 402.00
Other expenses	165.45	560.18	1 217.27
Total	**351.30**	**1 788.01**	**4 622.64**
Cost (US$/fish)			
Fertilizer	0.07	0.01	-
Feed	-	0.14	0.17
Other expenses	0.07	0.07	0.06
Total	**0.14**	**0.22**	**0.23**
Cost (US$/kg fish)			
Fertilizer	0.25	0.04	-
Feed	-	0.51	0.62
Other expenses	0.22	0.25	0.22
Total	**0.47**	**0.80**	**0.84**

Stocking density (fish/ha): extensive, 2 500; semi-intensive, 8 000; intensive, 20 000
Fertilizer includes chicken manure and inorganic fertilizers (21-0-0, 46-0-0, 16-20-0)
Cost of feed, US$0.38/lkg; assumed FCR: semi-intensive, 1.6, intensive, 1.8
Other expenses include cost of lime, fish seed/fry, labour, salaries, electricity, and diesel in semi-intensive and intensive systems
US$1.00 = 55.00 Pesos

Delay or non-payment of feed purchases. Because of low profits farmers will often delay payment for feed or not pay at all. This has a cascading effect back to the manufacturer, which in turn may lead to higher feed prices or may result in the closure of feedmills.

Underutilized feedmilling capacity. The animal feedmilling capacity in the Philippines is underutilized and yet many livestock and poultry feed manufacturers are switching to aquafeed production. This may lead to the demise of many small-scale manufacturers. The under-utilised capacity may be attributed to the price of feed, which forces the farmers to use other feeds such as trash fish and / or rice bran.

Preparation of farm-made feeds. The use of farm-made feeds and single-feed ingredients is an alternative way by which to reduce feed cost. However, on-farm feed manufacturing has not developed substantially in most areas because of the high capital requirements and the high cost and erratic supply of raw materials. Small farmers cannot compete with large feedmillers in the purchase of raw materials when these are in short supply. Large millers may receive 20–30 percent discounts for bulk purchase of ingredients

Nutritive value of feeds. The currently observed FCRs need to be reduced to improve income and profits.

Distribution and use of inorganic fertilizer. Fertilizers are frequently used in pond preparation but are not routinely used during the production cycle. Adequate fertilization protocols must be promoted to maximize the benefits of natural food. The cost of fertilizer distribution is high due to transport and inefficient port handling facilities (Aristorenas, 2000). There are malpractices in fertilizer trading such as under-weighing and adulteration, which the Fertilizer and Pesticide Authority cannot continuously monitor due to lack of funding.

Use of organic fertilizers and manure. Collection of manure from poultry and livestock in small-scale farms is seldom feasible because the animals are not usually confined. The use of compost in ponds could reduce production costs, though farmers are unenthusiastic about using compost because of high labour input requirements.

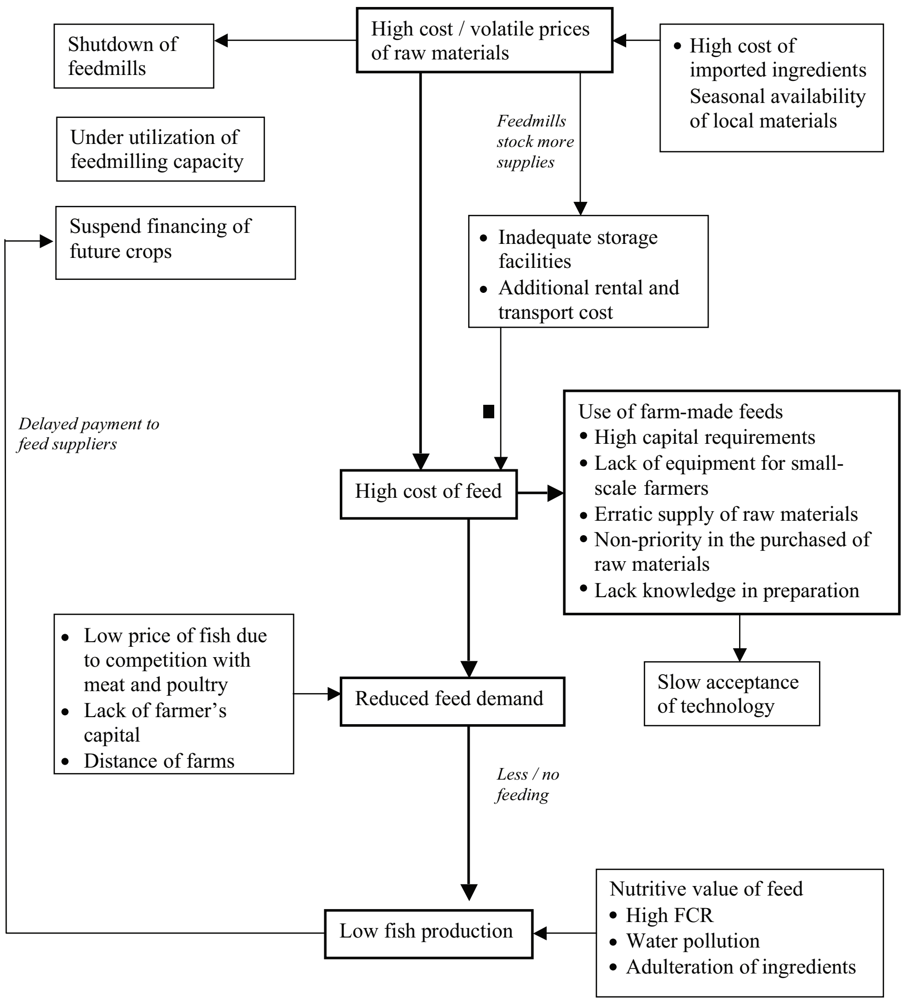
Other problems. The government does not have a national inventory of aquaculture systems and this precludes appropriate planning.

The problems and constraints that face the sector in the Philippines are schematically summarized in Figure 6.

5. RESOURCE AVAILABILITY AND THE EXPANSION OF THE AQUACULTURE INDUSTRY

Aquaculture production increased at an average of 7.2 percent per year during the period 1994 to 2004 with the highest growth registered in 2003-2004. Further expansion of the industry will depend on the availability of feed and fertilizer resources, allocation of suitable areas for expansion and technological advances in feed manufacturing and life support systems. The future requirements for feed and fertilizer are presented below

FIGURE 6
Problems and constraints of the aquaculture sector in the Philippines



Source: FPA (unpublished report)

and are based on projected fish production and FCRs. Fertilizer requirements were predicted based on pond area and recommended application rates.

5.1 Feed requirements

The projected feed requirements are based on available commercial feed consumption data. The average increase in the rate of production of various species over the past four to ten years in different culture systems was used to predict fish production and consequently the feed requirement of the industry (Table 30). It is predicted that milkfish pond culture will show the highest demand. Tilapia in ponds and cages will rank second, followed by milkfish in marine cages and pens, followed by tiger shrimp. Other species like catfish, grouper and mudcrab will eventually require substantial amounts of artificial feeds because of increasing production. Trash fish, as elsewhere in SE Asia, is becoming a limiting resource and every effort must be made to replace its use by artificial feeds in coming years. Assuming a linear increase in production of all species, the total feed requirement in 2014 is projected to be in the range of 1.34 million tonnes. This estimate could be the upper maximum as not all fish farmers will use manufactured feeds and FCRs will decrease.

TABLE 30
Current aquafeed production and future requirements (tonnes)

Species	Average growth during 1994-2004 (%/year)	Aquaculture production		Estimated feed production in 2003[b]	FCR	Feed requirement in 2014[c]
		2004	2014[a]			
Milkfish						
Brackish-water & freshwater pond	6.0	200 531	320 850	-	2.0	641 699
Brackish-water fish cage	6.0	4 056	6 490	-	2.0	12 979
Marine fish cage	6.0	23 179	37 086	-	2.5	92 716
Marine fish pen	6.0	14 173	22 677	-	2.5	56 692
Sub-total				16 974		804 086
Tilapia						
Brackish-water and freshwater pond	6.0	80 877	129 403	-	2.0	258 806
Freshwater cage and pen	6.0	64 779	103 646	-	2.0	207 293
Sub-total				29 908		466 099
Catfish	13.4	1 930	4 516	1 685	2.3	10 387
Grouper	5.5	170	264	-	2.3	606
Tiger shrimp	-0.8	35 916	33 043	11 472	1.8	59 477
Unspecified feed				114 356		
Total				**204 396**		**1 340 656**

[a] Predicted based on average growth rate of all species per year from 1994-2004, except for shrimp (1998-2004); [b] No available data for 2004; [c] Projected production x FCR

To establish whether the raw material supply can meet the demand of future aquafeed requirements an analysis was undertaken in which the requirements (Table 31) where juxtaposed with the projected available resources (Table 15). Energy sources like rice bran, corn bran and cornstarch are the most abundant feedstuffs. If the requirement for energy sources in 2014 will amount to some 717 000 tonnes (Table 31) then the projected available energy sources (10 158 171 tonnes, Table 15) will be adequate to cater for the needs of aquaculture. Coconut oil is the next most available resource but its use in aquafeeds is minimal. The total coconut oil requirement is only 3.6 percent of the projected total amount available. Other sources of oils such as soybean and fish oil must be developed to supply the need for n-3 and n-6 fatty acids in combination with coconut oil. The availability of copra meal and cake is adequate for all animal feed requirements. This commodity is only used in tilapia feeds such that the total aquaculture requirement for this material is low (4.2 percent of the total animal feed requirement). Because of the abundance of copra meal there is a real and urgent need for research and development to increase its use in aquafeeds. Domestic production of meat and bone meal can satisfy the needs of aquaculture. However, because of the requirements for swine feed the total supply will not be able to meet the demands of the animal feed industry as a whole. Soybean meal, which is the second most commonly used ingredient in aquafeeds (36 percent of total feed inputs), must be partially replaced by other legumes. All crustacean meal products are imported and this will not change. Some locally abundant ingredients are still underutilized and these are poultry by-product meal, feather meal and blood meal. These materials, if properly processed, could replace other feedstuffs that are in short supply and would assure the availability of feed ingredients for the future expansion of the aquaculture industry.

5.2 Fertilizer requirement

Fertilizers are needed in extensive and semi-intensive pond culture to promote natural productivity. The requirement for fertilizer depends on fishpond area. Given that the expansion of aquaculture in brackish waters is now prohibited this variable will be assumed to remain stable for the next 10 years. The medium term Philippine Development Plan 2004-2010, however, has allocated new areas for agribusiness that provides an additional 11 390 ha for milkfish and tilapia culture (NEDA, 2004). At an

TABLE 31
Estimated future requirements of feed ingredients for aquafeed production in the Philippines (tonnes)

Species	Feed requirement	Energy sources (rice bran/corn bran/wheat flour)	Copra meal/cake	Soybean meal	Fishmeal	Oils (fish/soybean/coconut)	Shrimp meal/ shrimp head meal	Blood meal
2003*								
Omnivore								
Milkfish	95 173	51 393	-	28 552	10 469	3 807	-	-
Tilapia	96 067	40 348	9 607	24 017	17 292	-	-	-
Catfish	1 685	-	-	-	-	-	-	-
Carnivore								
Grouper	minimal	-	-	-	-	-	-	-
Crustaceans								
Tiger shrimp	11 472	2 294	-	2 868	2 868	574	1 721	-
Total	204 397	94 036	9 607	55 437	30 629	4 381	1 721	-
2014								
Omnivore								
Milkfish	804 086	434 207	-	241 226	88 449	32 163	-	-
Tilapia	466 099	195 762	46 610	116 525	83 898	-	-	-
Catfish	10 387	4 155		3 116	234	519	-	-
Carnivore								
Grouper	606	133	-	36	121	36	61	121
Crustaceans								
Tiger shrimp	59 477	11 895	-	14 869	14 869	2 974	8 921	-
Total	1 340 656	646 152	46 610	375 773	187 572	35 693	8 982	121
% of total feed requirement		48.2	3.5	28.0	14.0	2.7	0.7	< 0.1

*No available data for 2004

Total inclusion levels (%): Energy sources - milkfish, 54; tilapia, 42; catfish, 40; grouper, 22; tiger shrimp, 20; mud crab, 27; copra meal/cake - tilapia, 10; soybean meal - milkfish, 30; tilapia, 25; catfish, 30; grouper, 6; tiger shrimp, 25; mud crab, 11; fishmeal - milkfish, 11; tilapia, 18; catfish, 20; grouper, 20; tiger shrimp, 25; mud crab, 25; oils - milkfish, 4; catfish, 5; grouper, 6; tiger shrimp, 5; mud crab, 5; shrimp meals - grouper, 10; tiger shrimp 15; meat and bone meal and blood meal - grouper, 20 (Based on standard formulations, in: Alava, 2002)

TABLE 32

Estimated fertilizer requirement for extensive and semi-intensive brackish-water pond culture in the Philippines

Region	Fishpond area (ha)[a]	Organic fertilizer requirement (tonnes)[b]	Inorganic fertilizer requirement (tonnes)[c]			
			16-20-0	18-46-0	46-0-0	21-0-0
CAR	-					
I	21 550	43 100	10 775	4 310	3 233	431
II	100	200	50	20	15	2
III	48 980	97 960	24 490	9 796	7 347	980
NCR	2 900	5 800	1 450	580	435	58
IV-A	5 850	11 700	2 925	1 170	878	117
IV-B	7 690	15 380	3 845	1 538	1 154	154
V	15 870	31 740	7 935	3 174	2 381	317
VI	58 720	117 440	29 360	11 744	8 808	1 174
VII	9 030	18 060	4 515	1 806	1 355	181
VIII	2 340	4 680	1-1 70	468	351	47
IX	25 010	50 020	12 505	5 002	3 752	500
X	4 150	8 300	2 075	830	623	83
XI	6 710	13 420	3 355	1 342	1 007	134
XI	3 260	6 520	1 630	652	489	65
XIII	5 830	11 660	2 915	1 166	875	117
ARRM	1 470	2 940	735	294	221	29
Total	219 460	489 998	109 730	43 892	32 919	4 389
Total production/ import (2003/2004)		52 388 734[d]	266 925	229 731	733 683	515 276
% of total production/import		0.9[e]	41.1	19.1	4.5	0.9

[a]Assuming no expansion in fishpond area; area for each region was determined by Landsat Image (NAMRIA, 2005) while total area is from Philippines Fisheries Statistics 2001-2003 (BAS, 2005a) and Philippines Fisheries Profile (BFAR, 2005).

[b]Assumed application rate: 1.5 tonne/ha in first cropping and 0.5 tonne/ha in second cropping.

[c]Assumed application rate: 50 kg/ha 16-0-0 or 20 kg/ha 18-46-0, 15 kg/ha 46-0-0, and 10 kg 21-0-0 applied during pond preparation and 1/2 of these rates every 15 days during four-month culture period; 21-0-0 is applied only during pond preparation; 2 crops/year (total inorganic fertilizer/year, 500 kg 16-20-0 or 200 kg 18-46-0, 150 kg 46-0-0, 20 kg 21-0-0).

[d]Production of chicken manure at 268g/day/2.3 kg animal (Whetsone 1974 in: Nash and Brown 1980)

[e](Total requirement / Total production and import) x 100.

application rate of 1.5 tonnes manure/ha for the first annual crop and 0.5 tonnes manure/ha for the second crop, the total aquaculture manure requirement in the Philippines is estimated to be 489 998 tonnes in 2003 and in the next 10 years (Table 32). A comparison of the data in Table 7 and 32 suggest that future manure supply will be adequate to meet the demands of pond aquaculture. The calculated requirement of inorganic fertilizers in 2004 based on recommended application rates and pond surface area is shown in Table 32. Most of the fertilizer requirements of the country will be imported.

6. RECOMMENDATIONS

On the basis of this review the following recommendations can be made for the future sustainable development of the sector in the Philippines. Several of the recommendations are considered to be of a general nature, while others specifically pertain to the more effective implementation of government programmes.

6.1 General

1. National research and development programmes on the use of other readily available raw materials for use in aquafeeds such as copra oilseed cake, legumes (e.g. cowpeas) and the promotion of soybean production should be established.
2. Strategies should be developed to monitor the quality and composition of available feed ingredients such as local fishmeal, rice bran, copra meals and oils such that farmers get better value for money.

3. The manufacture and use of farm-made feeds using locally available materials is recommended for small-scale fish farmers especially in remote areas and extension services and training programmes on feed preparation should be intensified in areas needing assistance.
4. Reducing feed costs through efficient feed conversion is the key to increasing returns. This requires further research on the nutrient requirements of aquaculture species.
5. There is a need to shift from using trash fish to cost-effective formulated feed.
6. Greater emphasis has to be given to the environmental impact of aquaculture. It is recommended that the environmental carrying capacity of major receiving waters in the country be established and that this should guide the expansion of the sector.
7. Nutrient discharge from shrimp farms should be minimized. Some shrimp farms already practice low-discharge techniques. There is a need to further refine and disseminate this technology to fish farmers.
8. According to the regional guidelines (SEAFDEC, 2005), a research-based quality standard for feeds and feed additives and guidelines for their proper selection and use should be established.

The recommendations made above offer significant opportunities for public/private partnerships involving farmers, feed manufacturers, private research institutes, universities and statutory institutions.

6.2 Effective implementation of government programmes

9. The further clustering of fish and shrimp farms and feedmills should be strongly promoted. The Department of Science and Technology (DOST), BFAR and the Department of Trade and Industry (DTI) have initiated such a program in some parts of the country.
10. The Balanced Fertilization Strategy (BFS) is an innovative and cost efficient approach for the use and management of location-specific combinations of inorganic and organic fertilizers. The BFS likewise aims to correct the declining rice production caused by fertilizer misuse and impact of urea overuse. This programme requires active support by all aquaculture stakeholders. The Department of Agriculture through the FPA has agreed to establish regional bulk blending facilities in strategic regional sites in the Philippines. This strategy is also applicable to and must be developed for the aquaculture sector.
11. The manufacture and use of compost must be promoted. The National Rapid Composting Programme should be strongly supported by all stakeholders and extension services must promote the programme among fish and shrimp farmers. Government should establish and disseminate guidelines for the appropriate selection and use of organic compost.

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Bureau of Agricultural Statistics
Bureau of Customs
Bureau of Fisheries and Aquatic Resources (Region III, IV-B, VI, VII, XIII, CAR)
Department of Environment and Natural Resources
Fertilizer and Pesticide Authority
National Mapping and Resource Information Authority

National Meat Inspection Service
National Statistics Office
Feed manufacturers and distributors
Ms Emerald Corpuz-Uy
Mr Philip Cruz
Mr Teodoro Cruz
Ms Arlene de la Vega
Mr Nelson Jardeleza
Mr Philip Ong
Mr Jun Toreda

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Analysis of feeds and fertilizers for sustainable aquaculture development in Thailand

S. Thongrod
Coastal Aquatic Feed Research Institute
41/14 Moo 9, Bangphra Sub-district, Sriracha District, Chonburi Province 20110
Thailand

Thongrod, S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Thailand. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 309–330.

SUMMARY

Fisheries play an important role in the national economy of Thailand. The export volume and value of fishery products in 2004 amounted to 1.66 million tonnes, valued at US$4 413 million. The total area under inland aquaculture in 2004 was 143 500 ha with a total production of approximately 523 709 tonnes. Over 50 percent of aquaculture production can be attributed to the central region of the country. The most important culture species are Nile tilapia (160 241 tonnes), hybrid clariid catfish (159 314 tonnes), Java barb (66 821 tonnes), snakeskin gourami, *Trichogaster pectoralis* (35 294 tonnes), giant freshwater prawn (32 583 tonnes) and sutchi catfish, *Pangasius hypophthalmus* (30 626 tonnes).

Marine aquaculture on the other hand has posted a rapid growth, particularly because of significant increases in shrimp and shellfish production. The most important mariculture species are black tiger shrimp *Penaeus monodon* and Pacific white shrimp (*Litopenaeus vannamei),* shellfish (green mussel, oysters and cockle), seabass and grouper.

Feed and feeding practices vary depending on the farming system and species as well as the destination (domestic market or export) of the final product. In the past, chopped trash fish was the feed of choice. However, because of the low farm-gate value, higher transport and fuel costs and the declining supply of trash fish, farmers have switched over to poultry by-products or other industrial food wastes. Industrial and agricultural by-products are either used as single or mixed feeds. Industrially manufactured, nutritionally complete feeds are generally used in intensive culture systems, especially in cages. These feeds are expensive and not always cost effective. However they are preferred due to their superior nutritive and physical properties. Farm-made feeds are less stable in water and are nutritionally inconsistent. This is largely due to the highly variable quality and nutritive composition of the raw materials. Farmers have limited knowledge of feed preparation and have no control over the quality of the ingredients they use as feed. Although, the government promotes the use of commercial aquafeeds, farm-made feeds are still widely used throughout the country. Extension support with respect to raw material selection, storage, processing of raw materials, feed formulation and preparation of farm-made aquafeeds must be improved.

The use of organic fertilizers in aquaculture has declined because of the increasing competition from agriculture. Moreover, the price of chicken manure is increasing and not as freely available as in the past because of the outbreak of bird flu in 2003. This has seriously affected integrated chicken or duck/fish farming.

Aquaculture in Thailand, including the industrial aquafeed industry, is a regulated activity and HACCP is implemented to ensure the quality of inputs and outputs. At the farm level, two quality assurance guidelines have been developed and adopted, viz., "Good Aquaculture Practice" (GAP) and a "Code of Conduct" (CoC) for shrimp farming. GAP emphasizes product freshness, cleanliness, freedom from drugs and chemicals and freedom from disease. CoC guidelines have been developed based on the philosophy of sustainable and environmentally responsible shrimp culture, hygiene and food safety.

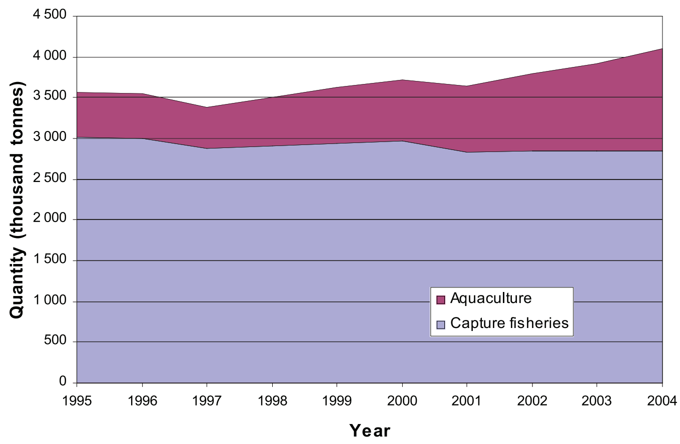
1. INTRODUCTION

Thailand is bound by the Gulf of Thailand in the east and the Andaman Sea in the west and has a coastline of 2 614 km, with many sheltered bays and lagoons. Inland water bodies include 66 rivers, 10 233 lakes and swamps and 685 reservoirs constituting a total water surface area of 566 400 ha (Tavaratmaneegul, 2001).

Fisheries continue to play an important role in the national economy of Thailand, which since 1997 has ranked among the top ten fish producing countries in the world. In 2004, the export of fishery products amounted to 1.66 million tonnes, valued at US$4 413 million, of which shrimp products accounted for US$1 683 million.

Aquaculture in Thailand has been practiced for more than 70 years and started with freshwater pond culture of snakeskin gourami (*Trichogaster pectoralis*). It continues to expand over the years, although the most rapid advances have been made in the last decade (Figure 1). Freshwater aquaculture continues to expand, while the area for coastal aquaculture has remained more or less the same (Table 1). For certain species, culture systems have changed from extensive to semi-intensive to intensive. Since 1998, inland aquaculture production has surpassed the inland wild catch (Table 2).

FIGURE 1
Capture fisheries and aquaculture production in Thailand during 1995-2004



Source: Fishery Information Technology Center (2006)

TABLE 1
Total area (ha) under inland and coastal aquaculture from 1999–2004

Year	Total	Freshwater	Coastal
1998	159 007	82 989	76 019
1999	168 580	91 036	77 544
2000	177 265	96 145	81 120
2001	177 494	100 553	76 941
2002	176 333	101 952	74 381
2003	193 921	111 902	82 019
2004	227 419	143 500	83 919

Source: Fishery Information Technology Center (2006)

TABLE 2
Capture fisheries and aquaculture production (thousand tonnes) in Thailand during 1992–2004

Year	Total production	Capture fisheries		Aquaculture	
		Marine	Inland	Coastal	Inland
1992	3 240	2 736	132	229	142
1993	3 385	2 753	175	296	162
1994	3 523	2 804	203	346	170
1995	3 573	2 827	192	358	196
1996	3 549	2 786	208	326	229
1997	3 384	2 680	205	300	200
1998	3 506	2 709	202	368	227
1999	3 626	2 725	207	442	253
2000	3 713	2 774	202	467	271
2001	3 648	2 632	203	535	280
2002	3 797	2 644	199	660	295
2003	3 914	2 651	198	703	361
2004	4 100	2 636	204	736	524

Source: Fishery Information Technology Center (2006)

2. GENERAL OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

Aquaculture practices in Thailand originated from traditional rice culture, from which wild fish were harvested as a by-product. This led to the proactive stocking of fish into ponds with improved fertilization regimens. The stocking density of fish in extensive culture systems is low at 500 fish/rai (1 rai = 0.16 ha) The most important extensive culture species are tilapia, common carp, rohu and Chinese carps. Some fish farms are integrated with poultry and/or pigs, and this is widely practiced in rural areas. The integrated culture of tilapia, sutchi catfish and chicken was very profitable. However, since the outbreak of bird flu in 2003/04, this practice is no longer well accepted as a farming system. Chicken farms have become bio-secure operations, such that any future outbreaks of the virus can be controlled.

Extensive aquaculture is still practiced in paddy fields, especially in Chachoengsao, Samut Prakan and Samut Sakhon provinces (Fishery Statistic Analysis and Research Group, 2005), though this practice is also decreasing, except in Samut Prakarn Province where snakeskin gourami is commonly grown in rice fields.

Semi-intensive polyculture is practiced in fertilized ponds in which fish are fed kitchen waste, slaughterhouse by-products or simple farm-made feeds consisting of rice bran, soybean oilseed cake and trash fish. Semi-intensive aquaculture is often integrated with poultry or pig farming. Nile tilapia and hybrid catfish are the two most common species cultured in these systems. The disadvantage of this practice is the low farm-gate price of fish in comparison to marine or freshwater carnivorous fish. Fish in these systems are mainly produced for local consumption using low-cost feeds. Formulated pellet feeds are generally not used in semi-intensive aquaculture. The farm gate value of tilapias cultured in ponds is US$0.63/kg. Stocking densities in semi-intensive systems vary between 50 000 and 62 500 fingerling/ha and production varies from 3 125–6 250 kg/ha. The pond size varies widely and ranges between 0.8 and 4.8 ha.

Intensive aquaculture is practiced in ponds and cages. The ponds are smaller and vary between 0.16–0.8 ha. The most commonly cultured species are hybrid catfish, Nile tilapia, hybrid tilapia/red tilapia (hybrid between Nile tilapia and Mozambique tilapia), snakehead and prawns. Although among tilapias, Nile tilapia is the species of choice, intensive culture of red tilapia is expanding because of its high market value (Figures 2 and 3). Feeds include poultry by-products, farm-made feeds or commercial

FIGURE 2
Culture of hybrid tilapia in cages in Mae Khong River, Nongkhai Province

FIGURE 3
Culture of hybrid tilapia in earthen ponds, Nakorn Rachasrima Province

pellets (floating or sinking). Stocking density of fish in intensive culture systems varies between 187 500–312 500 fingerlings/ha and reported yields vary from 9 375–50 000 kg/ha/crop for fish and 1 250–2 500 kg/ha/crop for prawns. The farm-gate value of cage-cultured fish is usually higher than pond-reared fish.

During the period 1992-2004, freshwater aquaculture production increased from 142 100 to 523 709 tonnes and in value from US$86.96 million to US$482.82 million. During the same period, the volume of coastal aquaculture production increased from 229 300 to 736 271 tonnes and in value from US$655.86 million to US$1 231.25 million (Fishery Information Technology Center, 2006).

2.1 Freshwater aquaculture

Over 20 species of freshwater fish are farmed in Thailand. The most important freshwater aquaculture species, with high export potential, are hybrid catfish *(Clarias gariepinus x C. macrocephalus*), Nile tilapia (*Oreochromis niloticus*), Java barb (*Barbonymus gonionotus*), snakeskin gourami (sepat siam in Thai) (*Trichogaster pectoralis*) and sutchi catfish (*Pangasius hypophthalmus*). Production of some of the more important freshwater fish from aquaculture and capture fisheries and their total value in 2004 are shown in Table 3.

The total area used for freshwater fish culture in 2004 was 143 501 ha (Table 4) with a reported production of 523 709 tonnes. Total production of freshwater fish by culture system and by species over the last five years (1999-2004) is shown in Tables 5, 6 and 7. In 2004, over 87 percent of total aquaculture production was from pond culture systems, while the outputs from paddy field, ditch and cage culture were 6.68, 1.08 and 5.17 percent, respectively (Table 5). Percent production of important freshwater species by intensity of aquaculture is shown in Table 8.

TABLE 3
Freshwater aquaculture production (tonnes) and inland capture fisheries and value (US$ million) in 2004

Species	Total production		Aquaculture	Capture fisheries
	Production	Value		
Nile tilapia (*Oreochromis niloticus*)	203 100	157	160 241	42 859
Common carp (*Cyprinus carpio*)	13 800	11	6 092	7 708
Java barb (*Barbonymus gonionotus*)	106 800	82	66 821	39 979
Snakeskin gourami/sepat siam (*Trichogaster pectoralis*)	37 800	38	35 294	2 506
Hybrid catfish (*Clarias macrocephalus x C. gariepinus*)	166 100	128	159 314	6 786
Snakehead murrel (*Channa striata*)	29 800	44	10 226	19 574
Sutchi catfish (*Pangasius hypophthalmus*)	33 700	21	30 626	3 074
Giant freshwater prawn (*Macrobrachium rosenbergii*)	33 000	97	32 583	417

Source: Fishery Information Technology Center (2006)

TABLE 4
Total area (ha) of productive fish farms and area under aquaculture during 1998–2004

Year	1998	1999	2000	2001	2002	2003	2004
Pond Culture	64 776	70 821	68 516	73 916	75 495	86 968	118 002
Paddy field	16 703	18 175	25 244	24 466	24 245	23 066	23 432
Ditch culture[1]	1 482	2 001	2 350	2 135	2 184	1 811	2 007
Cage culture	28	39	38	15	27	57	59
Total area	82 989	91 036	96 145	100 553	101 952	111 903	143 501

[1] Ditch is a man made waterway in plantations. Its width is normally less than 5 m. All ditches in plantation are connected to increase the space for cultured fish.

Source: Fishery Information Technology Center (2006)

TABLE 5

Total production (tonnes) of freshwater fish and yield (kg/ha) by culture system during 1998–2004

Year	Pond culture		Paddy field		Ditch culture		Cage culture		Total production
	Production	Yield	Production	Yield	Production	Yield	Production	Yield	
1998	206 738	3 190	13 151	790	5 406	3 650	1 629	58 510	226 923
1999	229 428	3 240	16 618	910	5 118	2 560	1 448	37 240	252 612
2000	240 907	3 520	19 936	790	6 707	2 850	3 462	90 910	271 012
2001	251 995	3 410	20 371	830	4 406	2 060	2 924	194 410	279 696
2002	266 461	3 530	20 602	850	4 113	1 880	3 325	123 700	294 501
2003	319 150	3 670	31 582	1 370	4 296	2 370	6 097	107 640	361 125
2004	455 981	3 864	34 967	1 492	5 659	2 820	27 102	459 359	523 709

Source: Fishery Information Technology Center (2006)

TABLE 6

Production (tonnes) of freshwater species during 2000–2004

Cultured species	2000	2001	2002	2003	2004
Nile tilapia (*Oreochromis niloticus)*	82 363	84 480	83 780	98 336	160 241
Mozambique tilapia (*O. mossambicus*)	26	30	27	19	149
Common carp (*Cyprinus carpio)*	5 539	4 773	5 046	4 457	6 092
Java barb (*Barbonymus gonionotus*)	46 276	42 152	44 242	49 066	66 821
Snakeskin gourami/sepat siam (*Trichogaster pectoralis)*	21 577	22 519	24 179	34 123	35 294
Chinese carps	438	202	202	200	286
Hybrid catfish (*Clarias macrocephalus x C. gariepinus)*	76 000	77 905	86 475	101 606	159 314
Snakehead murrel (*Channa striata*)	4 446	6 830	5 483	4 060	10 266
Giant snakehead (*C. micropeltes*)	81	87	95	145	193
Sutchi catfish (*Pangasius hypophthalmus*)	13 226	14 638	14 837	23 085	30 626
Marble goby (*Oxyeleotris marmorata*)	5	6	7	9.5	26
Giant gourami (*Osphronemus goramy*)	1 488	1 182	1 555	2 130	2 849
Rohu (*Labeo rohita*)	1 172	1 595	2 125	4 224	4 952
Bronze feather back (*Notopterus notopterus*)	5	4	5	66	1
Swamp eel (*Monopterus albus*)	38	38	25	43	50
Moon light gourami (*Trichogaster microlepis*)	169	154	165	290	538
Climbing perch (*Anabas testudineus*)	470	403	519	2 399	2 360
Small scale mud carp (*Cirrhinus microlepis*)	1 058	798	985	619	1 009
Giant freshwater prawn (*Macrobrachium rosenbergii*)	9 917	13 311	15 393	28 151	32 583
Frog (*Rana sp.*)	1 033	1 046	835	866	1 944
Soft-shelled turtle (*Trionyx cartilageneus*)	367	22 523	3 143	3 124	2 800
Others	5 313	5 012	5 373	4 095	5 332
Total production of cultured species	**271 012**	**279 696**	**294 501**	**361 125**	**523 709**

Source: Fishery Information Technology Center (2006)

TABLE 7

Aquaculture production (tonnes) by species and culture system in 2004

Species	Pond culture	Paddy field	Ditch culture	Cage culture
Nile tilapia (*Oreochromis niloticus)*	131 181	6 572	1 777	20 711
Common carp (*Cyprinus carpio*)	5 101	945	42	4
Java barb (*Barbonymus gonionotus*)	62 123	2 395	2 221	82
Snakeskin gourami/sepat siam (*Trichogaster pectoralis*)	13 905	21 353	35	1
Chinese carps	265	19	2	-
Hybrid catfish (*C. macrocephalus x C. gariepinus*)	153 658	316	783	4 557
Snakehead murrel (*Channa striata*)	8 250	1 953	22	1
Giant snakehead (*Channa micropeltes*)	183	0	0	10
Sutchi catfish (*Pangasius hypophthalmus*)	30 082	6	32	506
Giant freshwater prawn (*Macrobrachium rosenbergii*)	32 583	-	-	-
Marble goby (*Oxyeleotris marmorata*)	10	0	0	16
Giant gourami (*Osphronemus goramy*)	2 282	-	50	517
Rohu (*Labeo rohita*)	4 862	37	53	0
Swamp eel (*Monopterus albus*)	50	-	-	-
Moon light gourami (*Trichogaster microlepis*)	70	467	1	-
Climbing perch (*Anabas testudineus*)	1 164	868	327	1
Frog (*Rana sp.*)	1 931	1	-	12
Soft-shelled turtle (*Trionyx cartilageneus*)	2 797	-	3	0
Others	4 381	33	249	669
Total production	**455 981**	**34 967**	**5 659**	**27 102**
% of total production	**87.07**	**6.68**	**1.08**	**5.17**

Source: Fishery Information Technology Center (2006)

TABLE 8
Proportion (Percent) of total production by species and culture intensity in 2004

Species	Intensive system	Semi-intensive system	Extensive system
Nile tilapia	12.9	87.1	-
Common carp	-	84.4	15.5
Java barb	0.1	96.3	3.6
Sepat siam	-	99.9	0.1
Hybrid catfish	99.3	0.7	-
Snakehead	-	99.8	0.2
Sutchi catfish	99.9	-	0.1
Prawn	100.0	-	-

Source: Fishery Information Technology Center (2006)

2.2 Coastal aquaculture

In 2004, the production from coastal aquaculture (736 271 tonnes) accounted for approximately 58 percent of total aquaculture production (1 259 970 tonnes) (Table 2). The most important species are shrimps (*Penaeus sp*.), shellfish, mostly mussels, oysters and cockles, and fish such as Asian seabass/barramundi (*Lates calcarifer*) and grouper (*Epinephelus sp*.). Shrimp culture is the largest by volume and value.

2.2.1 Marine finfish farming

Seabass and groupers are the main cultured species in cages and earthen ponds. The production of marine finfish (Table 9) from cages (13 823 tonnes, 80.54 percent) exceeds that from ponds (3 339 tonnes, 19.46 percent) (Fishery Information Technology Center, 2006). Trash fish is used as a single feed and fed once a day in cages. Commercial pellet feeds for seabass are now available. However, trash fish is preferred as farmers are uncertain of profit margins using pelleted feeds. Moreover, the weaning of fingerlings of marine fishes on formulated feeds has not yet been perfected in Thailand.

Cage sizes for seabass and grouper culture vary from 20–50 m^3, with an average depth of 2 m. Seabass fingerlings are produced in hatcheries and stocked in cages at densities between 65–80 fish/m^3. Trash fish is used as food once a day at 3–5 percent of body weight (Sakaras, 1986). The grow-out period is 6–8 months, depending on the stocking size and the size at harvest varies from 600–800 g. Average feed conversion ratio is 7.5:1. Most seabass cages are family-owned businesses (Figures 4 and 5).

TABLE 9
Total production of marine finfish and the contribution from cages and ponds in 2004

Species	Total production (tonnes)	Cage culture (tonnes)	Pond culture (tonnes)
Seabass	13 588	10 615	2 973
Grouper	3 574	3 208	366
Total	**17 162**	**13 823**	**3 339**
% contribution		**80.54**	**19.46**

Source: Fishery Information Technology Center (2006)

FIGURE 4
Seabass reared in cages and fed on chopped trash fish once a day

Seabass and grouper production data, value and feed use are presented in Tables 10 and 11.

FIGURE 5
Seabass cages in Chachoengsao Province.
Cage-reared seabass are usually harvested when they reach marketable size of 600–800 g.

TABLE 10
Seabass and grouper production (tonnes) and feed consumption (tonnes)

Year	Seabass		Grouper		Total feed
	Production	Feed consumed[1]	Production	Feed consumed[1]	
1999	6 056	54 120	1 143	7 339	61 459
2000	7 752	70 040	1 312	8 299	78 339
2001	8 003	72 750	1 443	9 507	82 257
2002	11 032	97 300	1 170	7 794	112 894
2003	12 230	101 300	2 338	15 068	116 368
2004	13 588	108 700	3 574	23 231	131 931

[1] Trash fish consumption was calculated by using the average FCRs of 7.5 for seabass and 5.5:1 for grouper.
Source: Fishery Information Technology Center (2006)

TABLE 11
Total value (US$ million) of marine finfish culture

Year	1998	1999	2000	2001	2002	2003	2004
Grouper	9	8	9	10	7	12	30
Pond culture	1	2	2	1	1	2	3
Cage culture	8	6	7	9	6	10	27
Seabass	17	16	19	19	26	29	31
Pond culture	3	3	3	3	2	6	76
Cage culture	14	13	16	16	24	23	24
Total value	**26**	**24**	**28**	**29**	**33**	**41**	**61**

Source: Fishery Information Technology Center (2006)

2.2.2 Shrimp farming

Shrimp farming in Thailand started some 30 years ago with black tiger shrimp (*Penaeus monodon*) and banana shrimp (*P. merguiensis*). Shrimp were cultured in large rice fields of more than 4 ha using the traditional methods of tidal water exchange via a sluice gate and natural seed supply. Sluice gates were opened during the high tide to facilitate the entry of wild shrimp fry and nutrient rich water. Production from these extensive systems was unreliable and this gave rise to the current semi-intensive and intensive farming systems. Since the mid-1980s shrimp farming has spread to every coastal province in the country. In 2003, production from extensive systems was a mere 657 tonnes (0.02 percent of total shrimp production), while that from semi-intensive and intensive systems amounted to and accounted for 4 843 tonnes (1.07 percent) and 325 225 tonnes (98.34 percent), respectively.

TABLE 12

Cost of shrimp production in 0.16 ha ponds (Thai baht)

Item	Fixed cost	Variable cost	Total cost
Shrimp PL (100 000 fry)	11 000		
Feed cost (40.7% of total cost)		52 210	
Energy cost (20% of total cost)		25 656	
Manpower (1 person)	12 000		
Maintenance		27 389	
Total cost	**23 000**	**105 255**	**128 255**

Stocking density 66 fry/m^2; survival rate = 45.14%; average production per 0.16 ha pond = 780 kg; US$1.00 = Thai baht 40.00

Source: Tookwinas (2001)

The success of shrimp farming was supported by technological breakthroughs in shrimp hatchery and nursery technology and feed development. Total shrimp production has increased from 12 800 tonnes in 1982 to 360 289 tonnes in 2004 (Fishery Information Technology Center, 2006). The size of ponds under intensive farming conditions varies from 0.16–1.00 ha and these are stocked at densities ranging from 50–100 PLs/m^2, usually with black tiger shrimp. Shrimp are fed at least 4–5 times a day with high-quality commercial feeds and FCRs vary between 1.25–1.7:1, depending on the quality of feed and efficiency of feed management. A typical cost calculation for a shrimp farm is shown in Table 12. Shrimp ponds are normally aerated by paddle wheels or air/oxygen injectors are employed to maintain oxygen levels above 5 mg/l.

To address environmental problems culture systems have now evolved to zero discharge systems (Tunsutapanit *et al*., 1996), in which wastewater is treated and reused in the grow-out ponds. Regulations have also been introduced for shrimp farm registration and effluent regulation to mitigate against negative effects of shrimp farms on the coastal environment. The Department of Fisheries (DoF), Thailand has also introduced several programs to promote the production of quality shrimp to safeguard consumers and to prevent export rejections (Tookwinas and Keerativiriyaporn, 2004), namely the "Guideline for Good Aquaculture Practice" (GAP) and the Code of Conduct (CoC). GAP emphasizes the production of shrimp that are fresh, clean, drug residue free and not contaminated with disease and dirt. The CoC guidelines were developed on the philosophy of environmentally sustainable shrimp culture and the hygienic production of shrimp that are safe for consumers, in accordance with CODEX, ISO14001/(EMS) and the FAO Code of Conduct for Responsible Fisheries. These initiatives have been implemented to increase consumer confidence in the quality and safety of Thai shrimp, to promote environmentally responsible shrimp farming in Thailand and for the benefit and protection of farmers (Songsangjinda and Tatttanon, 2004).

The CoC guidelines are also a strategic development to comply with international requirements of the world shrimp market. These development programs have been effectively monitored through HACCP throughout the country (Tookwinas, 2002). Residues in cultured shrimp are also monitored before harvesting and certified for both export and local consumption.

The followings measures are taken for controlled and safe shrimp production in Thailand.

1. Registration of farms
2. Technical assistance for the controlled use of feeds/antibiotics
3. Monitoring of residues in farmed shrimp
4. Mobile control unit to monitor diseases and the use of antibiotics and feeds
5. Monitoring water quality of both inlet and outlet of farms
6. Inspection of farm hygiene and post-harvest handling practices
7. Training farmers on GAP, safe uses of chemotherapeutic agents and handling practices

3. REVIEW AND ANALYSIS OF AQUACULTURE FEEDS AND FEEDING

Thailand produces formulated feeds for herbivorous fish, carnivorous fish and shrimp. Commercial pellet feeds are commonly used in shrimp aquaculture, but are not well accepted by fish farmers who still largely rely on farm-made feeds. This is mainly due to the low value of most fish. However, recent fuel price increases have affected the price of trash fish and other feed ingredients normally used in farm-made feeds. Hence, farmers are trying to develop new formulations and feed management practices to reduce the cost of production. For herbivorous fish, pond fertilization with animal manures is practiced to increase natural food production. However, the high competition for organic fertilizers from agriculture has reduced the availability of fertilizers for fish farming.

3.1 Feed and feed ingredients

In Thailand, feed ingredients and commercial feeds are expensive. Feed generally accounts for more than 60 percent of the total production cost, especially for freshwater fish. In the past, chopped trash fish was the principal feed ingredient of choice (Jantrarotai and Jantrarotai, 1994; Sitasit, 1994; Thongrod, Jintasataporn and Boonyaratpalin, 2004). However, because of the low farm gate value of fish and the escalating price of trash fish farmers have changed to poultry by-products or other

TABLE 13
Nutritional value of some feed ingredients used in aquafeed in Thailand

Ingredients	Nutritional value (% dry matter)						
	Moisture	Crude protein	Crude lipid	Ash	Crude fibre	NFE*	Source of information
Feed ingredients of animal origin							
Fishmeal (Thai origin) 50% crude protein (CP)	10.0	49.1	-	-	-	-	1
Fishmeal 55% CP	8.0	55.0	8.0	26.0	1.0	2.2	1
Fishmeal 60% CP	8.0	60.0	10.0	19.0	-	3.0	1
Squid by-product	8.1	74.8	8.8	3.4	-	4.9	3
Shrimp head meal	10.0	41.8	4.3	34.0	9.9	-	1
Mackerel viscera	69.0	16.0	12.0	-	-	-	3
Chicken by-product meal	6.5	57.5	15.0	15.6	2.3	3.1	3
Chicken head	38.8	26.9	26.4	7.6	0.3	-	3
Chicken viscera	73.7	13.9	11.2	1.2	-	-	3
Poultry feather meal	10.0	83.5	2.5	2.5	1.5	-	1
Meat and bone meal	7.4	49.1	10.3	29.9	2.6	0.7	3
Blood meal	10.4	81.5	1.0	4.8	0.7	1.6	3
Feed ingredients of plant origin							
Rice hull	10.0	12.2	11.8	13.1	12.3	40.6	3
Defatted rice hull	9.0	13.9	1.0	15.0	13.0	48.1	1
Rice bran	12.0	8.0	0.9	0.7	1.0	77.4	1
Soybean meal, full fat	5.9	36.2	19.8	4.6	5.5	28.0	2
Soybean meal, defatted	11.8	44.6	1.5	5.8	6.1	30.3	2
Soybean protein concentrate	9.3	61.3	0.4	5.5	5.6	17.9	2
Soybean hull (grade 1)	10.0	42.0	4.7	5.7	6.7	30.9	3
Soybean hull (grade 2)	10.0	44.0	1.0	6.0	7.0	32.0	1
Soybean hull (grade 3)	10.0	48.5	1.0	6.0	3.5	31.0	1
Spirulina meal	6.0	66.4	0.4	6.4	9.4	11.5	2
Mung bean hull	10.8	18.4	1.7	3.4	17.8	47.8	2
Palm oil kernel	10.0	18.5	1.5	3.6	14.2	52.2	1
Peanut hull	7.0	48.0	5.8	5.1	7.0	27.1	3
Cassava	13.5	2.2	0.5	5.0	3.0	75.8	3
Cassava leaf	12.0	19.0	5.6	7.0	26.0	30.4	1
Corn grain	12.2	9.6	3.9	1.5	2.0	70.8	1
Corn meal	11.2	9.4	0.2	1.2	0.8	77.2	3
Coconut by-product	10.0	21.0	6.0	7.0	12.0	44.0	1
Lupin leaf	10.0	20.2	3.5	8.8	18.0	39.5	1
Distiller waste	10.0	26.0	6.0	4.0	12.0	42.0	1
Green fodders							
Duckweed	91.9	1.7	0.5	0.9	0.9	4.0	3
Water lettuce (*Pistia stratiotes*)	91.9	1.2	0.4	-	1.8	2.9	3
Alligator weed (*Alternanthera* sp.)	77.5	3.2	0.8	-	2.6	11.6	3
Water hyacinth (*Eichhornia* sp.)	94.9	1.0	0.2	-	0.9	1.8	1

*Nitrogen-free extract

Source: [1] Kasetsart University (1999); [2] Boonyaratpalin *et al.* (2003); [3] Sitasit *et al.* (1982)

industrial food wastes. Many ingredients are used for farm-made feeds and commercial feeds. Except for soybean meal, these ingredients are locally available. Soybean meal is imported from the United States of America and China and is used mainly for the production of nutritionally complete commercial feeds. The nutritional value of selected feed ingredients commonly used in Thailand is presented in Table 13. For marine fish farming, trash fish is still used as a single feed for both the nursery stage and for grow-out. The DoF is presently promoting the replacement of trash fish with commercial feeds for the rearing of marine fish species.

3.2 Freshwater fish feeding practices

3.2.1 Herbivorous fish

Most herbivorous fish are cultured in extensive or semi-intensive systems, except for tilapia. Aquaculture of herbivorous fish in extensive culture system primarily depends upon natural food produced by fertilization with organic manure, inorganic fertilizer or a combination of both. Commonly used pond fertilization practices are presented in Table 14.

Chicken manure is expensive and is now often unavailable for fish farming. This is due to the bird flu (Highly Pathogenic Avian Influenza) disease outbreak in 2003. This has negatively affected integrated fish farming. Chicken manure is currently only available from large industrial farms in Thailand and these are bio-secure systems.

Feeds such as rice bran are evenly distributed over the pond or put in feeding bags. Under semi-intensive and intensive farming conditions compound feeds that consist of aquatic plants, rice bran, broken rice, trash fish or poultry by-product are provided in feeding bags. The mixtures are also cooked and processed into wet dough, extruded through a meat mincer and fed in a moist form or sun dried.

TABLE 14
Pond fertilization practices in Thailand

Type of fertilizer	Rate of application
Lime ($Ca(OH)_2$)	200 g/m²
Organic fertilizer - chicken, duck or buffalo manure	125–250 g/m²
Crop waste, rice straw	5 truck container/ha
Inorganic fertilizer - urea	2–3 g/m²

Source: farmer interview

Tilapia cage culture

Tilapia cage-culture systems are described by Sihapitakgiat *et al* (2000). Cage volumes vary from 25–40 m³ with an average depth of 2 m. Tilapia fingerlings are stocked into the cages at between 25–100 g. The rearing period varies from 3–5 months, depending on size. Fish are fed with floating catfish pellets twice per day. A feeding schedule for tilapia is illustrated in Table 15.

The average weight of tilapia at harvest varies between 800 g and 1.2 kg and FCRs range from 1.24–1.5:1, depending on feed quality. The farm-gate value of tilapia depends on fish size and type of culture (Table 16). The price of cage-cultured tilapia is double that of fish reared in ponds. FCRs in pond culture are between 1.7–1.8:1. The difference in FCR is a consequence of the protein levels, which under pond farming conditions are lower than that of the feeds fed to fish in cages.

TABLE 15
Feeding schedule for tilapia cage culture

Stocking size	Rearing period	Feed no.	Protein content (%)	Average weight (g) at harvest	FCR
25 g	1 month	1	32		
	2–3 months	2	30		
	4–5 months	3	25	800–1 200	1.24–1.5
40 g	57 days	3	25	200	
	130 days	3	25	625	
100 g	3 month	3	25	600	

Source: farmer interview

TABLE 16
Farm-gate price of tilapia reared in cages and in ponds

Size of fish (g)	Cage culture (US$/kg)	Pond culture (US$/kg)
Less than 600 g	0.75	0.38
600–800	0.95	0.63
800–1200	1.00–1.05	0.75

Source: farmer interview

Climbing perch (Anabas sp.) culture

Pond culture of climbing perch (*Anabas* spp.) is becoming increasingly popular. It is easy to manage in small ponds, ranging between 400–1 600 m². Advantages of climbing perch culture include a short culture period of three months, high production and high value. Fry are stocked at 1 cm in length at about 20 fingerlings/m². They are fed with catfish feed for three months and reach 70–150 g with a total production of 700–800 kg/400 m² pond. Feed conversion ratio varies between 1.4–1.5:1 and the farm-gate price depends on size, ranging from US$0.63 for 75 g fish to US$1.75/kg for 170 g fish. It is likely that aquaculture of climbing perch will increase substantially in the near future.

3.2.2 Carnivorous and omnivorous fish

The most important carnivorous and omnivorous freshwater fish are hybrid clariid catfish, snakehead and sutchi catfish. Culture systems vary according to the intensity of inputs and stocking density and the type of culture system adopted (e.g. monoculture, polyculture or integrated fish culture) depends on the chosen species. Omnivorous species like tilapia, Java barb, common carp, Chinese carp and mrigal are polycultured, while carnivorous species like clariid catfish, snakehead, sutchi catfish, freshwater prawns and sand goby are generally chosen for monoculture (Dey, Paraguguas and Alam, 2001).

Catfish grow-out ponds are between 300–2 000 m² and 1–1.5 m deep. Fingerlings of 2–3 cm are stocked at 40–100 fish/m², depending upon availability and price, as well as the intended production practice (Jantrarotai and Jantrarotai, 1994). Juvenile fish are fed mainly on formulated pellet, whereafter farmers switch to cheaper farm-made feeds. These consist of trash fish, cooked broken rice and rice bran or of chicken viscera, chicken head and bones and rice ban (Kosutarak, 1999). The composition of typical farm-made feeds is shown in Table 17. Thongutai (1969) reported superior growth of fish fed with farm-made feeds containing trash fish and rice bran (9:1) in comparison to those fed on pelleted feed only, in which fishmeal and soybean meal were used as protein sources. Na-nakorn (1995) recommended that fresh feed should be used as a supplement

TABLE 17
Typical formulation of a farm-made hybrid clariid catfish feed (perecent as fed basis)

Formula	Ingredients (%)					Nutritional value (%)		Cost of feed (baht/kg)
	Distillers waste	Chicken bone	Chicken head	Chicken viscera	By-product from soy sauce	Crude protein (%)	Crude lipid (%)	
1	12	-	-	80	8	17.4	6.1	2.13
2	8	-	4	80	8	17.6	6.8	2.21
3	8	-	8	76	8	18.0	7.6	2.34
4	8	-	12	72	8	18.4	8.4	2.47
5	8	-	16	68	8	18.8	9.3	2.60
6	16	-	-	76	8	17.6	6.2	2.18
7	12	-	4	76	8	17.8	6.9	2.26
8	12	-	8	72	8	18.2	7.7	2.39
9	12	-	12	68	8	18.6	8.5	2.52
10	12	-	16	64	8	19.0	9.3	2.65
11	20	-	-	72	8	17.8	6.2	2.23
12	8	12	-	72	8	17.6	6.1	2.35
13	8	16	-	68	8	17.7	6.2	2.44
14	8	20	-	64	8	17.8	6.2	2.53
15	12	12	-	68	8	17.8	6.2	2.40
16	12	16	-	64	8	17.9	6.2	2.49
17	12	20	-	60	8	18.0	6.3	2.58
18	-	20	-	72	8	17.4	6.0	2.43
19	-	-	20	72	8	18.8	9.9	2.63
20	-	16	12	64	8	18.5	8.4	2.73

Source: Surasak farm, Nakhon Ratchasima Province to floating pellets. A formulated pellet feed for catfish (NIFI 12), containing 56 percent fishmeal, 12 percent dehulled peanut meal, 12 percent rice bran, 14 percent starch, 4 percent fish oil, 1 percent vitamin and mineral premix and 0.4 percent binder is available on the market (Sitasit, 1985). The average FCR obtained on formulated pellets ranges from 1.5–2:1. The rearing period is between 3 and 6 months depending on the intended harvest size, which ranges between 100 and 300g and production levels of between 10–14 tonnes/rai are normally achieved. A catfish feeding schedule has been developed by the DoF that farmers have adapted according to their experiences. Generally the fish are fed twice a day on a ration that decreases from around 40 percent biomass per day to between 3 and 4 percent of biomass at the end of the growing period. Summary information including total production, feed cost and farm gate value is presented in Table 18.

TABLE 18
Rearing costs of hybrid clariid catfish in a 0.8 ha pond

Total production	5 000 kg
Survival rate	80%
Average fish size	250 g
Farm-gate price	US$0.7/kg
Total farm gate value	US$3 500
Total feed cost	US$2 045
Profit	US$1 456

Source: farmer interview

TABLE 19
Feed and feeding practices for a typical 1 rai sutchi catfish pond stocked with 10 000 fingerlings

Age	Feeding duration	Type of feed	Amount of feed
1–15 days	2 weeks	Floating pellet	5–10 kg in total (2 weeks)
	2 weeks	Chicken bone	50 kg/day
2 months	1 month	Chicken bone	50 kg/day
		Commercial feed	5 kg every other day
3 months	1 month	Chicken bone	100 kg/day
		Commercial feed	5 kg every other day
4 months	1 month	Chicken bone	150 kg every other day
		Commercial feed	5 kg every other day
5 months	1 month	Chicken bone	200 kg every other day
		Commercial feed	5 kg every other day
6 months	1 month	Chicken bone	200 kg every other day
		Commercial feed	5 kg every other day

Source: farmers' interview

TABLE 20
Feed use and cost for a 1 rai sutchi catfish pond stocked with 10 000 fingerlings

Feeding duration	Chicken bone		Commercial feed	
	Amount (kg)	Price (US$)	Amount (kg)	Price (US$)
1st month	1 500	150	5–10	2.5–4.5
2nd month	3 000	300	75	33.75
3rd month	3 000	300	75	33.75
4th month	2 250	225	75	33.75
5th month	3 000	300	75	33.75
6th month	3 000	300	75	33.75
Total	**15 750**	**1 575**	**450**	**171–173.25**

Source: farmers' interview

Sutchi catfish (Pangasius hypophthalmus) farming

Sutchi catfish culture is widely practiced in central Thailand. The fingerlings (3 cm average length) are stocked in 0.16 ha (1 rai), 2 m deep earthen ponds, at a density of 6.25 fingerlings/m^2. Feed type and feeding practices and feed use and costs are described in Tables 19 and 20, respectively. The average FCR obtained on poultry by-product is 3.33:1, average size at harvest after 6 months is 1.5–2 kg and total production is about 5 tonnes/rai. The average farm-gate price in 2005 was US$0.55/kg. Ponds are often fertilized with pig manure at 1 200 l (wet weight) per week.

TABLE 21
Ingredient composition and nutrient content of feed commonly used for larvae of clariid catfish[1] and tilapia fry (percent as fed basis)

Ingredients	Catfish larvae	Catfish larvae	Catfish / tilapia larvae	Tilapia larvae
Cassava starch	-	15	15	15
Rice bran	-	3	10	30
Wheat gluten	25	0	0	0
Fishmeal	50	72	65	47
Fish oil	7	7	7	5
Di-calcium phosphate	1	1	1	1
Premix[2]	2	2	2	2
Binder[3]	15	-	-	-
Total	100	100	100	100
Calculated nutritional composition				
Crude protein	45.0	40.0	37.5	30.0
Crude lipid	10.9	12.5	12.0	10.0
Ash	12.1	18.3	17.6	16.3
Crude fibre	0.7	1.6	2.2	3.8
NFE	24.9	19.6	22.2	31.6
Energy (kcal/kg)	3 000	3 000	3 000	2 800
Feed cost (baht/kg)	39.96	19.15	18.13	15.1

[1] Both walking catfish and hybrid catfish
[2] Vitamin and mineral premix for freshwater fish are commercially produced and sold in the market
[3] Binder included primarily cassava starch and rice flour.
Source: Thongrod, Jintasataporn and Boonyaratpalin (2004)

4. FEED MANAGEMENT STRATEGIES

In both semi-intensive and intensive farming, feed is the most important and expensive input. The production and supply of poultry by-products has been constrained by the changes that the industry has had to make after the outbreak of bird flu in 2003. This has also influenced aquaculture as the demand for poultry offal is increasing in response to the declining availability and increasing price of trash fish in many parts of the country.

The major problems surrounding the use of farm-made feeds are associated with the quality and supply of primary ingredients. Farmers find it extremely difficult to control the quality of the feeds they produce, which results in unpredictable production and environmental pollution. Farm-made feeds consist of trash fish or poultry offal or both, cooked broken rice, rice bran, soybean meal, agricultural by-products and vitamin and mineral premixes. Most farmers now use poultry by-products as the primary ingredient, which in most instances has to be delivered on a daily basis, as they do not have appropriate cold storage facilities. Farmers can also choose from a number of different fishmeal based formulations developed by the DoF and other research institutions. Some of these are shown in Tables 21, 22 and 23. Catfish fingerling feeds are often fortified with mackerel viscera, which acts as an attractant resulting in improved FCRs. Feed bags

TABLE 22
Farm-made practical feed formulation for clariid catfish[1] (percent as fed basis)

Ingredients	Ingredient composition/ fish size		
	Fingerling (1st 3 months)	Grow-out 1 (2nd 3 months)	Grow-out 2 (3rd 3 months)
Dried cassava meal	26	22	22
Coconut by-product	-	-	20
Rice bran	-	15	-
Soybean meal	41	32	32
Fishmeal	25	20	20
Lupin leaf	-	5	-
Fish oil	5	3	3
Di-calcium phosphate	1	1	1
Vitamin and mineral premix	2	2	2
Total	**100**	**100**	**100**
Nutritional composition			
Protein	32.00	28.00	28.00
Lipid	8.02	6.28	6.66
Ash	11.69	11.93	10.73
Fibre	3.62	5.44	5.28
Gross energy (kcal/kg)	2 800	2 700	2 600
Feed cost (Baht/kg)	11.86	10.18	9.78

[1] Both walking catfish and hybrid catfish
Source: Thongrod, Jintasataporn and Boonyaratpalin (2004)

TABLE 23
Farm made practical feed formula for tilapia and other herbivorous fish (percent as fed basis)

Ingredients	Ingredient composition/ fish size			
	Fingerling to 2-4 months	Grow-out (cage)	Grow-out 1 (pond)	Grow-out 2 (pond)
Dried cassava meal	23	23	35	22
Coconut meal	-	-	-	30
Rice bran	15	20	15	-
Soybean meal	30	25	25	25
Fishmeal	25	25	20	20
Lupin leaf	-	-	-	-
Fish oil	4	4	2	-
Di-calcium phosphate	1	1	1	1
Vitamin and mineral premix	2	2	2	2
Total	**100**	**100**	**100**	**100**
Nutritional composition				
Crude protein	31.00	30.00	26.80	29.86
Crude lipid	7.44	7.53	5.01	4.11
Ash	12.57	12.76	11.40	10.67
Crude fibre	4.25	4.40	4.20	6.05
NFE	35.80	36.30	42.88	40.22
Gross energy (kcal/kg)	2 700	2 700	2 500	2 500
Feed cost (Baht/kg)	11.30	10.65	9.36	8.50

Source: Thongrod, Jintasataporn and Boonyaratpalin (2004)

are also used to reduce wastage, particularly in tilapia culture. Two recommended feed formulations for seabass and marine shrimp are shown in Tables 24 and 25, respectively.

TABLE 24
Recommended feed formulae for seabass (*Lates calcarifer*) (percent as fed basis)

Ingredients	Percentage composition	
	Formula 1	Formula 2
Thai fishmeal	63.0	70.0
Rice bran	-	9.0
Shrimp head meal	6.8	-
Soybean meal	11.9	-
Alpha starch/wheat gluten	6.0	12.4
Tuna oil	4.5	1.5
Soybean oil	4.5	3.0
Trace mineral premix	2.0	2.0
Vitamin premix	1.0	2.0
Vitamin C	0.1	0.1
Sodium monophosphate	0.2	-
Total	**100.0**	**100.0**
Proximate composition (%)		
Moisture	7.40	6.48
Crude protein	44.23	41.8
Crude lipid	13.91	9.64
Ash	18.57	16.66
Crude fibre	2.19	0.87
NFE	13.71	24.56

Source: Boonyaratpalin (1991)

TABLE 25
Recommended feed formulae for grow out of black tiger shrimp (*Penaeus monodon*) (percent as fed basis)

Ingredients	Percentage composition	
	Formula 1	Formula 2
Thai fishmeal	28.0	33.0
Shrimp head meal	10.0	10.0
Squid visceral meal	4.0	4.0
Soybean meal	20.0	16.0
Wheat gluten	5.0	7.0
Wheat flour	20.0	-
Tuna oil	2.5	0.5
Vitamin Premix	2.0	2.0
Trace Mineral Premix	2.0	2.5
Vitamin C	0.48	0.1
BHT	0.02	-
Lecithin	1.0	-
Binder	-	1.5
Rice bran	5.0	23.4
Total	**100.0**	**100.0**
Calculated proximate composition (%)		
Moisture	10.49	9.24
Crude protein	37.02	43.29
Crude lipid	7.53	5.77
Ash	10.47	14.39
Crude fibre	2.46	4.38
NFE	32.04	22.93

Source: Manual for feed preparation, Department of Fisheries, adopted from Boonyaratpalin and New (1994)

TABLE 26
Nutritional value (%) of feeds under legislative control in Thailand

Feed	Form of feed	Size of feed particle	Crude protein (min)	Crude lipid (min)	Crude fibre (max)	Moisture (max)	Cost (US$/ kg)
Marine shrimp feed							
- Zoea – Mysis stage	Powder Flake	<100 µm Not defined	>40	>6	<3	<10	Vary
- Mysis stage	Powder Flake	100–250 µmµ Not defined	>40	>6	<3	<10	Vary
- Post larvae 1–5 (P1– P5)	Powder Flake	200–500 µmµ Not defined	>40	>6	<3	<10	Vary
- Post larvae 5–15 (P 5–P 15)	Flake Crumble	Not defined Ø<0.5–0.71 mm	>40	>6	<3	<10	0.92
- Juvenile (1.2–2.5 cm)	Pellet	Ø<0.5–0.71mm	>38	>5	<3	<11	0.92
- Juvenile (2.5–3.5 cm)	Pellet	Ø<0.71–1.68mm	>38	>5	<3	<11	0.91
- Juvenile (1–3 g)	Pellet	Ø<1.68–2.38mm	>38	>5	<3	<11	0.90
- Fingerling (3–12 g)	Pellet	Ø1.6–2.38 mm	>36	>4	<4	<12	0.89
- Medium shrimp (12–30 g)	Pellet	Ø1.8–2.4 mm	>35	>4	<4	<12	0.77
- Large shrimp (> 30 g)	Pellet	Ø2.2–2.6 mm	>35	>3	<4	<12	0.76
Supplementary shrimp feed	Pellet	Not defined	>32	>3	<4	<12	
Freshwater prawn feed							
- Juvenile - 1 month old	Crumble	Not defined	>37	>5	<3	<10	0.53
- 1– 3 months old	Pellet	Not defined	>30	>4	<5	<12	0.52
- 3 month - harvest size	Pellet	Not defined	>25	>3	<6	<12	0.51
- Large prawn	Pellet	Not defined	>25	>3	<6	<12	0.44
Herbivore fish feed							
- Fingerling	Pellet	Not defined	>28	>3	<8	<12	0.33
- 150–250 g fish	Pellet	Not defined	>25	>3	<8	<12	0.32
- >250 g fish	Pellet	Not defined	>20	>3	<12	<12	0.32
Catfish feed							
- Fingerling 4–15 days old	Powder	Not defined	>35	>5	<6	<12	1.23
- From 16–30 days old	Pellet		>35	>4	<6	<12	0.53
- From 30–45 days old	Pellet		>30	>4	<6	<12	0.51
- Medium size (<3 months)	Pellet		>28	>3	<8	<12	0.51
- Large size from 3 months – harvest			>24	>3	<8	<12	0.48
Carnivorous fish: snakehead							
- Fry	Powder		>40	>3	<4	<12	
- Fingerling	Crumble/pellet		>37	>4	<4	<12	
- Medium size	Pellet		>35	>4	<5	<12	
- Large fish			>30	>4	<6	<12	
Marine fish feed:							
- Fry	Powder	Sinking feed	>42	>5	<4	<12	
- Fingerling	Crumble/Pellet	Sinking feed	>40	>5	<4	<12	
- >50 g fish	Pellet		>38	>5	<4	<12	0.89
- >300 g fish			>35	>5	<5	<12	0.86
Frog Feed- 100 g frog	Pellet		>35	>4	<7	<12	0.61

Source: Thai Animal Feed Manufacturing Association (2004).

5. REVIEW OF THE DEVELOPMENT OF THE AQUAFEED INDUSTRY

Aquaculture in Thailand has expanded rapidly since 1986 and this has increased the demand for high-quality formulated feeds. At present there are about 60 feed mills in the country. Of these 34 produce only shrimp feed and 12 produce only fish feed, while the others produce both fish and shrimp feeds. In addition there are several companies that manufacture feed additives and premixes.

5.1 Feed quality control

The rapid increase in the demand for and production of aquafeeds has caused shortages of ingredients and this has resulted in inconsistent feed quality. Poorly formulated feeds and/or improper manufacturing processes have resulted in low digestibility and poor water stability. Legal quality controls for marine shrimp, freshwater prawn, catfish and herbivorous fish feeds that requires the industry to manufacture feeds according to certain quality standards and to register and license their feeds were introduced in 1991 (Agriculture and Cooperatives Ministry Regulation 1991). Similarly, all imported feeds have to be registered and licensed by the Department of Livestock Development. Further details of the regulations are provided by Sitasit (1995) and the Aquafeed Quality Control and Development Division (2002). The nutritional value of feeds has to be clearly indicated and feeds are regularly sampled and tested. Feed factories may not produce medicated feeds. Similarly, wholesalers and retailers of aquafeeds must also be registered and licensed. In 1999 the legislation was amended to include commercial feeds for carnivorous marine and freshwater fish, soft-shell turtles and frogs. The average shelf life of commercial feeds is three months; hence the manufacture and expiration date must be stated. Factories are inspected regularly to maintain standards as laid down by law. The nutritional value of feeds under legislative control in Thailand and the current prices of feeds are given in Table 26.

5.2 Aquafeed production and import and export of feed ingredients

There is a high degree of competition among feed manufacturers in Thailand. This has been to the advantage of farmers who, as a consequence, have access to high-quality feeds at a competitive price. Estimated total production of compounded feed for livestock and aquaculture and utilization of major feed ingredients during 2000-2004 are shown in Table 27. Aquafeed production and consumption have increased substantially over the years (Table 28). In 2001, Aquafeed consumption was 660 000 tonnes, which increased to 1.07 million tonnes in 2005. Table 28 also illustrates the

TABLE 27

Estimated total feed production (animal and aquafeed) and ingredient utilization during 2000–2004 (in thousand tonnes)

	2000	2001	2002	2003	2004
Total feed production	9 311.1	9 734.2	10 515.3	10 720.0	9 858.5
Fishmeal	493.2	465.3	482.4	582.5	611.4
Corn	4 186.0	4 164.0	4 263	4 151.0	4 000.0
Full fat SBM	249.2	325.7	329.7	348.1	
Defatted SBM	1 722.0	1 961.0	2 064.0	2 632.0	2 281.8
Broken rice	455.7	735.0	381.8	398.6	981.0

Source: Thai Animal Feed Manufacturing Association (2004)

TABLE 28

Aquafeed production and ingredient use during 2001–2005

	Shrimp/fish	Production (tonnes)	Feed consumption (tonnes)	Fishmeal		Soybean meal		Corn	
				% in feed	Amount (tonnes)	% in feed	Amount (tonnes)	% in feed	Amount (tonnes)
2001	Shrimp	240 000	480 000	35	168 000	12	57 600	0	
	Fish	279 700	180 000	20	36 000	22	39 600	35	63 000
Total		**519 700**	**660 000**		**204 000**		**972 200**		**63 000**
2002	Shrimp	315 000	630 000	35	220 500	12	75 600	0	0
	Fish	294 500	217 350	20	43 470	30	65 205	30	65 205
Total		**609 500**	**847 350**		**263 970**		**140 805**		**65 205**
2003	Shrimp	280 000	560 000	35	196 000	12	67 200	0	0
	Fish	321 000	262 500	20	52 500	30	78 750	30	78 750
Total		601 000	822 500		248 500		145 950		78 750
2004	Shrimp	260 000	520 000	35	182 000	12	62 400	0	0
	Fish		262 500	20	52 500	30	78 750	30	78 750
Total			**782 500**		**234 500**		**141 150**		**78 750**
2005	Shrimp	400 000	672 000		107 200		121 600		0
	Fish	-	402 000	20	80 400	30	120 600	30	120 600
Total			1 074 000		187 600		242 200		120 600

Source: Thai Animal Feed Manufacturing Association (2004)

TABLE 29
Average price of local and imported feed ingredients during the last 2 years (baht/kg)

Local ingredients	2004	2005	Imported	2004	2005
Cassava	3	4	Wheat bran	4.28	4.49
Corn	6	6	Wheat gluten	47.11	42.06
Rice bran	5	5	Soybean grain	12.96	11.89
Broken rice	8	8	Wheat flour	15.85	13.88
Defatted soybean	14	12	Defatted soybean	14.61	11.51
Shrimp head meal	16	16			
Fishmeal	23	22	Fishmeal	31.58	32.79
Squid oil	44	40	Squid oil	44.35	40.40
Squid liver meal	73	61	Squid liver powder	26.72	29.70
			Fish oil	35.08	37.92

Source: Thai Animal Feed Manufacturing Association (2004)

type and volume of some of the ingredients used in aquafeed production. Feedmillers in Thailand are faced with high ingredient import tariffs, which range between 5-20 percent for the most important ingredients. There are no restrictions regarding import volumes and time frames for fishmeal, although only fishmeal with a protein content of 60 percent and above may be imported. A tariff of 15 percent is imposed on fishmeal imported from outside the ASEAN alliance, and 5 percent on fishmeal imported from ASEAN. However, there are rather severe import restrictions on corn. While tariff rates on corn imports have been liberalized, the benefit of this reduction has been offset by the requirement that corn should only be imported between March and June. Corn is subjected to a tariff-rate quota: in-quota corn imports (54 440 tonnes) are subjected to a 20 percent tariff rate, while out-of-quota corn imports are subject to a 73.8 percent tariff. There are unlimited import quotas for soybean, for which the import duty is five percent. However, Thailand requires that importers purchase a certain amount of domestically produced soybean product before being granted a license to import product. The price of some imported ingredients, such as squid and squid liver meal, is cheaper than the domestic product, because soybean meal is added to reduce the moisture content, while the local product is pure. The average prices of local and imported aquafeed ingredients are shown in Table 29.

About 10 000 tonnes of fishmeal is imported per year from three countries: Peru (76.2 percent), Denmark (9.5 percent) and Chile (4.2 percent). To protect the local industry, the government only allows importation of high-protein fishmeal (>60 percent). This fishmeal is mainly used for shrimp feed production. Soybean production in Thailand is low (269 300 tonnes in 2003) in comparison to the requirement of 1.95 million tonnes. Corn production (4.2 million tonnes in 2003) approximately matches the current requirements of the animal feed industry.

6. PROBLEMS AND CONSTRAINTS

Trash fish based farm-made feed is considered as one of the most suitable feeds for many fish species. However, the price of trash fish has increased to such an extent that its use as a primary feed ingredient is declining rapidly. This is mainly due to competition from fishmeal manufacturers for the by-catch, fuel price hikes and a decline in by-catch landings. Consequently, farmers now use slaughterhouse by-products (mainly chicken offal – intestines, heads, feet, bones) as the primary ingredient for farm-made feeds. The outbreak of bird flu in 2003 was a disaster and has constrained the use of farm-made feeds. It is estimated that there were over 333 500 fish farms in 2003 (Fishery Information Technology Center, 2005), many of which previously relied on trash fish and latterly on chicken offal. This has placed an enormous strain on the sub-sector and competition for fresh trash fish and slaughterhouse by-products has become intense.

There are no standard farm-made feed formulations. In general, the composition of the feed depends on the availability and price of local raw materials. Hence, the nutritional values of the feeds are highly variable, resulting in unpredictable production. Moreover, most farmers cannot store adequate quantities and have to purchase small quantities. Improper storage results in spoilage, poor fish growth and water pollution. In view of escalating costs this has become a major constraint for many farmers.

Farm-made feeds are generally made using simple equipment such as meat mincers and most often fed in a moist form. This causes water pollution and increases the risk of disease in comparison to manufactured commercial pellets. Farmers with adequate cash flow can afford to acquire additional equipment such as a hammer mill, mixer and cookers and are thus able to improve feed quality.

Feed management practices are largely inadequate. Many farmers simply dump the mixed raw materials into the fish pond once a day. This leads to feed losses, water quality problems and reduces the profitability of the enterprise.

The increasing price of organic manure is becoming problematic for fish farmers. Price escalation is related mainly to competition for chicken manure from agriculture and reduced availability because of bird flu. Poor farmers and those in rural areas are most affected, while those with a good cash flow can afford to purchase adequate quantities.

In Thailand, industrially manufactured feed is used mainly for shrimp farming and in intensive fish- cage and pond-culture systems, and especially for those fish that are primarily destined for export. If manufactured feeds are to be used to feed fish destined for local consumption, then it is incumbent upon feed manufacturers to invest in research on the nutritional requirements of all life-history stages of these species, such that low-cost feeds can be produced. It is anticipated that the demand for imported feed ingredients such as fishmeal, soybean meal and corn meal will increase. Although rice bran and broken rice are locally available there is likely to be shortage. The use of manufactured feeds is also constrained by farmer perceptions that the feeds are too expensive. Hence there is a need to educate farmers to calculate production costs and profit margins. This would go a long way towards assisting the farmers to adopt best feeding practices.

7. CONCLUSIONS AND RECOMMENDATIONS

Feed and feeding constraints in inland aquaculture vary depending on the farming systems (semi-intensive or intensive), type of feed used (farm-made feeds or commercial feeds) and species as well as whether the fish are produced for local consumption or for export. Feed manufacturers are still increasing production volumes, suggesting that the demand for aquafeeds is increasing. It is predicted that manufactured feeds will be the only viable option to ensure the sustainable development of freshwater and coastal aquaculture in the future, especially for products destined for export.

There is a need for government to set up extension projects to compare complete feeds with farm-made feeds. Simultaneously feed manufacturers must pay greater attention to the use of alternative and cheaper ingredients. The use of formulated feeds would also reduce the use of organic manures.

Farm-made feeds are less stable in water and inconsistent in nutritional value in comparison to commercial feeds and this leads variable fish production. Farmers have little knowledge of feed preparation and processing technology and of raw material quality control. While the government promotes the use of commercial feeds, farm made-feeds are still indispensable in some areas, especially where fish are produced primarily for domestic consumption. Hence, there is a need for government to provide extension support to farmers on the selection, storage and processing of raw materials and on the formulation and preparation of farm-made feeds. Such support should be adequately backed up by on-farm action with respect to sourcing and testing of new raw materials, formulation and feed processing, and research on the development of low-cost equipment to produce farm-made aquafeeds. In this regard, government and the feed industry should make better use of farmer associations and feed distributors to disseminate information and new technologies. In addition, there is a need for training workshops, demonstration ponds and study tours, particularly for rural small-scale farmers.

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APPENDIX

Inland aquaculture systems in Thailand

A.1. Characteristics of inland aquaculture systems and practices in Thailand

System	Aquaculture species	Average size of pond (ha)	Stocking density (nos./ ha)	Feed and feeding	Rearing period (days/months)	Harvest size (g/kg)	Production (kg/ha)
Extensive							
Paddy field culture	Sepat siam	>1		Fertilization / natural food			1 250 kg/ ha
Polyculture	Tilapia and sutchi catfish	1	21 000-28 000	Vegetable waste and fertilization			
Semi-intensive							
Polyculture in pond	Tilapia and hybrid catfish	0.8	50 000 -62 500	Chicken by-product	6-8 months	Nile tilapia 500 g, Hybrid catfish 250 g	3 125 – 6 250 kg/0.8 ha
	Nile tilapia and sutchi catfish	0.3	5 000 + 5 000	Chicken by-product	6-8 months	Tilapia 0.5- 1 kg; sutchi catfish 1.5-2 kg	5 000 kg /0.3 ha
Intensive culture							
Pond	Tilapia, Java barb, catfish and common carp			Fertilization / commercial feed / kitchen waste / poultry by-product			
Cage	Climbing perch	400 m^2	8 000/cage	Commercial catfish feed	3 months	70-150 g	700-800 kg/400 m^2
	Tilapia 25-40 g	25-40 m^3		Commercial feed	3-5 months	800g – 1.2 kg	
	Tilapia 40g each	12.4 m^3	60/m^3	Floating pellet	57 – 130 days	200 – 625 g	43.6 kg/m^3
	Sutchi catfish			Commercial feed			
	All male tilapia	28.8 m^3	2 000/cage	Herbivorous fish feed (30% CP)	4.5 months	700 g	1500 kg/cage
	All male tilapia (25 g)	62.5 m^3 (5x5x2.5 m)	1 500/cage	Herbivorous fish feed	4 months	350- 500 g	600-650 kg/cage

Stocking density is expressed in number per ha unless otherwise indicated.

Analysis of feeds and fertilizers for sustainable aquaculture development in Viet Nam

Le Thanh Hung and Huynh Pham Viet Huy
Faculty of Fisheries
Nong Lam University, Ho Chi Minh City
Viet Nam

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SUMMARY

Aquaculture in Viet Nam has become an important economic activity. Total production in 2004 exceeded 1.22 million tonnes, accounting for approximately 40 percent of the country's total fisheries output. Seaweed, fish, crustaceans and molluscs are produced in a wide array of freshwater and marine culture systems at various levels of intensity under mono or polyculture conditions.

Extensive aquaculture is practiced in ponds, rice fields and reservoirs. Chinese, Indian and common carp are the preferred fish in these systems and animal manure is the principal input. Improved extensive and semi-intensive aquaculture is practised in ponds with higher levels of nutrient and feed inputs. Integrated livestock/fish farming is being promoted to optimise the use of on-farm nutrient resources. Intensive aquaculture is undertaken mainly in smaller ponds, cages and tanks. Snakeheads, pangasiid catfish and red tilapia are main species produced in intensive freshwater systems. Trash fish is the most important feed or feed ingredient for snakeheads and pangasiid catfish, while pellets and farm-made feeds are the main inputs in intensive catfish and red tilapia aquaculture systems.

Coastal aquaculture is dominated by black tiger shrimp (*Penaeus monodon*) farming, particularly in the Mekong Delta and coastal provinces of Central Viet Nam. There have been significant advances in the intensification of shrimp farming in Viet Nam. Most shrimp farms are now operated on a semi-intensive scale, while intensive shrimp farming is making rapid advances. Shrimp in intensive systems are fed on commercially manufactured pellet feeds, while semi-intensive and improved extensive system employ trash fish as the major feed ingredient. Other marine species farmed in Viet Nam include eight grouper species, Asian seabass/barramundi (*Lates calcarifer)*, cobia (*Rachycentron canadum*), yellowtail/greater amberjack (*Seriola dumerili*), seabream and snapper and four species of lobster of the genus *Panulirus*. Trash fish is the principal feed for all of the above marine species.

The aquafeed industry in Viet Nam started in 1998. In 2004, the industry produces 300 000–350 000 tonnes of pelleted feed for fish and 150 000–200 000 tonnes of shrimp feed. Despite these developments farm-made feeds still play a vital and major role in Vietnamese aquaculture. Trash fish is the major component of farm-made feeds. However, the supply of trash fish is limiting the development of the sector, unless rapid advances are made to reduce the cost of manufactured feeds. Bulk of fishmeal, soybean meal, wheat flour and marine by-products used by feed manufacturers are imported.

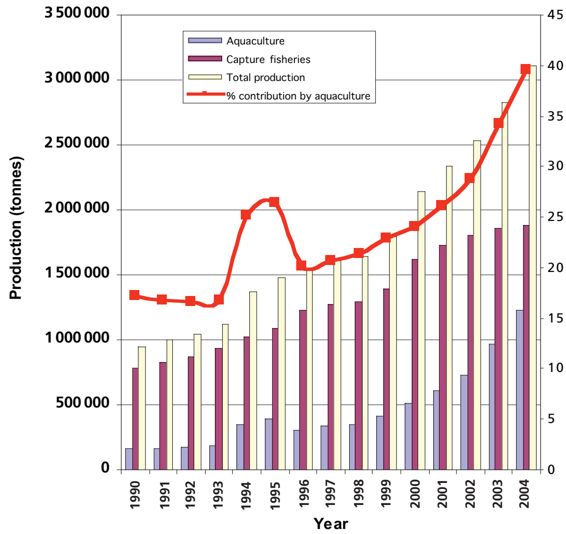
Aquaculture in Viet Nam is targeted to grow at over 20 percent per annum to 2010. To attain this national goal it is essential that aquaculture becomes more intensive. It also means that more feed and nutrient inputs are needed and this poses several challenges that have to be met. The challenges revolve particularly around the availability and supply of feed ingredients and the dwindling supply of trash fish. For the sector to develop in a sustainable manner there is a need to focus on alternatives to fishmeal and trash fish, farmer education and for government to formulate enabling policy and legislation to facilitate the development of the aquatic feed industry.

1. GENERAL OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

1.1 Current status of aquaculture

The inland and marine aquatic resources of Viet Nam are ideally suited for aquaculture development. The country has a coastline of around 3 260 km, 12 lagoons, straits and bays, 112 estuaries and thousands of islands in the China Sea. Inland waters include a network of rivers, canals, irrigation systems and reservoirs amounting to about 1.7 million ha that consists of 120 000 ha of ponds, lakes and canals, 340 000 ha of reservoirs, 580 000 ha of paddy fields in which aquaculture is integrated with rice farming and 660 000 ha of tidal waters.

FIGURE 1
Fisheries and aquaculture production in Viet Nam during 1990 and 2004



Source: FAO (2006)

TABLE 1
Fisheries and aquaculture production (tonnes) and their export value (thousand US$) during 2002, 2003 and 2004 and target for 2010

Sectors	2002	2003	2004	2010
Total fisheries production	2 530 639	2 823 607	3 108 105	-
Aquaculture production	728 041	967 502	1 228 617	2 000 000
- Inland aquaculture	441 827	547 931	703 827	946 000
- Brackish & marine	286 214	419 571	524 790	1 054 000
Export value of fisheries and aquaculture production	-	2 199 577	2 397 000	-

Source: Production data from FAO (2006) and export value data from MOFI (2004)

The total fisheries production of Viet Nam reached about 2.53 million tonnes in 2002 and increased to more than 3.1 million tonnes in 2004, of which more than 1.22 million tonnes was from aquaculture (FAO, 2006). Figure 1 shows the development of aquaculture in Viet Nam between 1990 and 2004. Freshwater aquaculture is the largest contributor to total aquaculture production (57.3 percent), followed by brackish-water aquaculture with 27.6 percent and mariculture with 15.1 percent. Since 1990 aquaculture production has been increasing continuously over the years and Viet Nam is currently acknowledged as having the fastest aquaculture growth rate in Asia. The target of the national fisheries development plan is for Viet Nam to produce 2.0 million tonnes of aquaculture produce in 2010 (Table 1) (MOFI, 2004).

Capture fisheries seem to be reaching a plateau. Fortunately the rapid increase in aquaculture production has compensated for the production gap such that the country can meet the increasing demand of its domestic and international markets.

1.2 Inland Aquaculture

Inland aquaculture in Viet Nam is well developed and in 2004 accounted for 57 percent of national aquaculture production (FAO, 2006). The sections below describe the various systems that are in use and the species that are cultured in them.

Pond culture is the most common aquaculture practice in the country. The main aquaculture species include common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), grass carp (*Ctenopharyngodon idella*), Indian major carps (*Labeo rohita, Cirrhinus cirrhosus*), tilapias (Mozambique tilapia *Oreochromis mossambicus* and Nile tilapia *O. niloticus*),

TABLE 2
Catfish area and production trends in the Mekong Delta

Category	1997	1999	2001	2003	Estimated 2004	Growth rate %/year
Culture area (ha)	**1 290**	**2 253**	**2 305**	**2 717**	**3 200**	**24.6**
- Pond (ha)	1 290	2 253	2 288	2 652	2 991	21.9
- Cage (unit)	1 300	1 621	2 539	2 271	1 872	7.3
Production (tonnes)	**40 250**	**86 775**	**114 289**	**162 778**	**255 044**	**88.9**
- Pond	22 550	50 330	66 660	109 105	178 624	115.3
- Cage	700	19 005	37 418	48 068	45 748	-

*Culture area includes both ponds and pens and so the values in some cases slightly differ from that of pond area. Cage area have not been included in the culture area.

Source: MOFI (2004)

hybrid clariid catfish (*Clarias macrocephalus* x *C. gariepinus*), and Mekong catfish (tra catfish *Pangasius hypophthalmus and* basa catfish *P. bocourti*). Pond culture is practiced at different levels of intensity. At the household level most small-scale farmers practice extensive polyculture in fertilized ponds, in which the fish rely entirely on natural food. Cyprinids and tilapias are the most commonly used species in these systems. Semi-intensive and intensive practices are geared more towards the production of high value fish and freshwater prawns, such as hybrid clariid catfish, pangasiid catfish, giant snakehead (*Channa micropeltes*), red tilapia (hybrid between Nile tilapia and Mozambique tilapia), kissing gourami (*Helostoma temmincki*) and giant freshwater prawn (*Macrobrachium rosenbergii*).

Cage culture is practised along the Mekong River, its tributaries (the Tien and the Hau) and in the Delta and in reservoirs. Cage culture is permitted only in the larger reservoirs such as Hoa Binh (19 000 ha), Thac Ba (18 000 ha), Tri An (32 400 ha), Thac Mo (10 600 ha) and Dau Tieng (18 000 ha). Reservoir cage culture species include grass carp, marble goby (*Oxyeleotris marmorata*), snakehead, common carp, hybrid clariid catfish and red tilapia, while the species grown in cages in the Mekong river and delta include three species of pangasiid catfish (*P. bocourti*, *P. hypophthalmus* and *P. conchophilus)* as well as hybrid clariid catfish (Tuan, 2003).

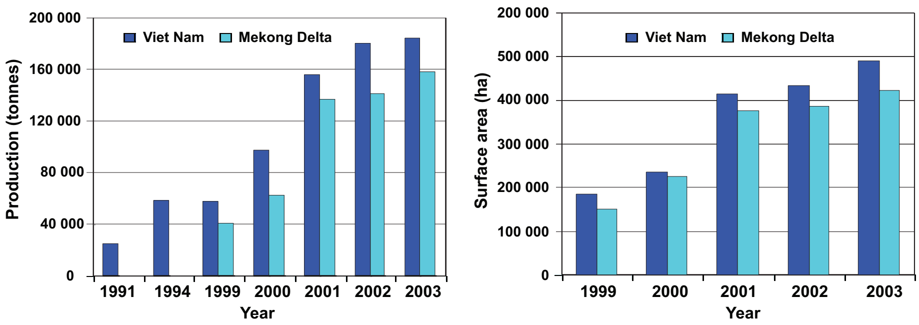
Pen culture of pangasiid species, particularly *P. hypophthalmus,* is a relatively new practice that is being developed, along with pond culture, for pangasiid catfish in the Mekong Delta marshes. Some 30 672 tonnes of catfish were produced in pens in 2004. Pen culture of *P. hypophthalmus* already contributes 12 percent of total pangasiid catfish production in the Delta.

The Mekong Delta is the most important freshwater aquaculture region in Viet Nam and therefore requires special mention. Many culture practices are applied and various fish species are cultured in this area. Indian major carps, Chinese carps, silver barb and tilapia are produced for domestic consumption, while pangasiid catfish, marble goby and freshwater prawns are exported. Freshwater prawn farming in the Delta has led to substantial diversification of farming practices, such as the increase in rice fields and integrated rice-prawn farming systems. Mekong catfish farming in the Delta has expanded at an extremely rapid rate (Table 2) and is unquestionably the most important species in the Delta. Production in 2004 was around 280 000 tonnes, accounting for 56 percent of freshwater aquaculture production in the Delta and about 10 percent of the national aquaculture export value (Phuong *et al*., 2005).

1.3 Coastal Aquaculture

Coastal aquaculture is dominated by pond culture of black tiger shrimp, particularly in the Mekong Delta and the central provinces of Viet Nam. The diversity of coastal aquaculture is however best summarized on a regional basis. The marine species farmed in Viet Nam are described by Tuan (2003).

FIGURE 2
Production and pond surface area of shrimp farming in Viet Nam and the Mekong Delta



Source: MOFI (2003)

1.3.1 Coastal aquaculture in the Mekong Delta

The rapid development of shrimp farming in the Mekong Delta since 1999 is illustrated in Figure 2. Marine fish, brine shrimp (*Artemia*) and mud crab are also commonly cultured species in the Delta. Between 1999 and 2003 total shrimp farming area had increased by more than 2.8 folds (160 000 ha to 450 000 ha) and production by over 3.8 times during this period. In 2003, about 450 000 ha were dedicated to shrimp farming in the Delta and production had reached 162 000 tonnes (MOFI, 2003) Currently the Delta is responsible for 86 percent of national shrimp production and comprises about 87 percent of the country's total shrimp pond area.

Shrimp farms include extensive, improved-extensive, semi-intensive and intensive systems. Extensive shrimp farming (80–250 kg/ha/year) is being gradually replaced by semi-intensive and intensive systems, with higher production levels of 6–10 tonnes/ha/crop. Rice-shrimp farming is also widely practiced, which has several advantages and synergistic effects.

1.3.2 Coastal aquaculture in the central provinces

Tiger shrimp is also the most important aquaculture species in the coastal areas of the central provinces. In 2003, this region had some 16 931 ha under shrimp ponds and shrimp here are farmed intensively (MOFI, 2004). Lobsters and groupers are cultured in cages. Edwards, Tuan and Allan (2004) reported that lobster (*Panulirus* spp.) cage culture was more profitable than grouper culture. In Khanh Hoa province there are over 12 000 lobster farms. Lobster culture is mainly a family enterprise, with each family owning one or more cages that are deployed in coastal lagoons or sheltered bays. Cages are typically 10–30 m^3 in volume, constructed with synthetic netting stretched over a bamboo frame. Floating cages, supported by plastic drums, are also used. Families tend to aggregate their cages in areas where water quality is good and to benefit from lower labour costs and improved security (Hambrey, Tuan and Thuong, 2001). Other species cultured in the central provinces include red grouper, black grouper, snapper, shrimp and ornamental fish.

1.3.3 Coastal aquaculture in northern Viet Nam

Coastal shrimp and fish aquaculture activities in northern Viet Nam are concentrated mainly in the Gulf of Tonkin. Cat Ba Island, Ha Long Bay, Do Son (Hai Phong province), Quang Ninh, Nam Dinh, Ninh Binh, Thai Binh, Thanh Hoa, Nghe An and Ha Tinh. Cage culture of Asian seabass (*Lates calcarifer*) and cobia (*Rachycentron canadum*) is mostly located on Cat Ba Island and in Ha Long. Trash fish is the main feed used in cage culture. Trash fish food conversion ratios (FCR) are high (6–8:1) and some farmers are now also using pelleted feed. Both tiger shrimp and Pacific white shrimp (*Litopenaeus vannamei*) are farmed in northern Viet Nam, mainly around Quang Ninh, Hai Phong, Nam Dinh, Ninh Binh, Thai Binh, Thanh Hoa, Nghe An and Ha Tinh.

2. ON FARM FEEDING PRACTICES AND FEED MANAGEMENT STRATEGIES

2.1 Inland Aquaculture Systems

A total of 29 species (14 indigenous and 15 introduced) are farmed in freshwaters in Viet Nam (Table 3).

More than 70 percent of the freshwater aquaculture species are omnivores and include, amongst others Mekong catfish, hybrid clariid catfish, Indian major carps, kissing gourami (*Helostoma temminkii*) and red tailed tinfoil/silver barb (*Barbonymus altus*) (Table 4). All the cultured carnivorous species are indigenous and high value species such as snakehead (giant snakehead *Channa micropeltes* and snakehead murrel *C. striata*), marble goby and spotted bronze featherback (*Notopterus notopterus*). Almost all of the filter feeders are introduced species. Overall, omnivorous species are the most favoured because they are able to feed on a variety of feeds such as rice bran, fresh manure, cooked rice, trash fish, vegetables, restaurant waste, etc. (Hung, 2004).

2.1.1 Pond fish culture

Pond culture of herbivorous fish

Herbivorous fish are preferred in household-scale culture systems that primarily produce fish for home or local consumption. In particular grass carp and silver barb are popular species and they are fed on aquatic plants and grass, which are abundant, and supplemented with rice bran, manure, restaurant waste and household waste when available.

Pond culture of filter feeders

Silver and bighead carp, catla, rohu and sometimes tilapia are classified as filter feeders, although tilapia can also be considered an omnivore. Polyculture systems have been developed for the culture of filter feeders in which farmers raise 3–5 species in fertilized ponds. Silver and bighead carp are favoured in northern Viet Nam and the central Highland, while catla and rohu are preferred in the Mekong Delta.

Animal manure (pig, duck, chicken and cattle) is the main input for polyculture systems in Viet Nam. The use of manures is diverse and is described below. However, farmers lack knowledge of application procedures and rates. Except in fingerling ponds, farmers rarely use inorganic fertilizers to stimulate natural productivity (Hung, 2004).

TABLE 3
Families and the number of freshwater aquaculture fish species in Viet Nam

Family	Total number of species	Indigenous species	Introduced species
Cyprinidae	12	3	9
Pangasiidae	4	4	-
Ophicephalidae	3	3	-
Cichlidae	3	-	3
Anabantidae	4	2	2
Clariidae	3	2	1
Total	**29**	**14**	**15**

Source: Hung (2004)

TABLE 4
Feeding guilds of freshwater aquaculture fish species in Viet Nam

Feeding guild	Species
Herbivores (3)	Grass carp, snakeskin gourami (*Trichogaster pectoralis*), silver barb (*Spinibarbus denticulatus*)
Filter feeders (4)	Silver carp, bighead carp, tilapias
Omnivores (21)	Mekong catfish (*P. hypophthalmus, P. bocourti*), hybrid clariid catfish, Indian major carps, giant gourami (*Osphronemus goramy*), kissing gourami, silver barb, etc.
Carnivores (5)	Snakeheads (*Chana gachua, C. micropeltes, C. striata*), marble goby, bronze featherback (*Notopterus notopterus*).

Number within parenthesis is the number of species under the specified feeding guild.

2.1.2 Animal-fish integrated systems

Integrated fish-livestock farming is widely practised throughout the country. Most common is the pig-fish combination. Waste products from pig production are the main source of nutrient input. Herbivores and planktivores make optimum use of algal and zooplankton blooms, while omnivores make direct use of the pig manure. In this way, farmers maximize the use of on-farm resources without additional cost for feeds. Pig stocking density is usually in the range of 150–200 pigs/ha of fishpond with an initial weight of 30–50 kg. Fish are usually stocked at a density of 7 fish/m^2. Pig "compost" can also be obtained from biogas generators, which is then used for pond fertilization. Under these conditions the fish are normally fed with rice bran (50–70 percent) and crab, golden snail or other fish or agricultural processing by-products. Typical production figures of several livestock-fish combinations are provided in Table 5.

TABLE 5
Fish production in various freshwater farming systems

Farming systems	Yield (tonnes/ha/crop)
Rice-fish integrated	0.43–0.80
Pig-fish integrated	3.88–7.59
Fish-rice alternative	0.60–0.90
Prawn-rice alternative	0.75–0.80
Prawn-rice integrated	0.35–0.50

Source: Wilder and Phuong (2002)

VAC systems (V="Vuon" or garden, A="Ao" or fishpond, C = "Chuong" or pig coop) are also popular. The system is designed to optimally use most on-farm waste resources. Main feed inputs to fish ponds are agricultural by-products such as rice bran, vegetable, cassava leaf, corn meal, etc. and waste (manure and uneaten food) from the pigs. Fish produced in the VAC systems are normally low value fish used for household consumption or for sale in local markets. Grass carp, common carp, silver carp and Indian carps are commonly used.

2.1.3 Rice-fish integrated system

The Mekong Delta has more than 1.0 million ha of rice paddies, of which 400 000 ha are suitable for developing rice-fish culture (Tuan *et al*., 1995, cited by Hao *et al*., 2000). However, many factors such as flooding and low rice prices have affected rice-fish integrated farming systems in the Delta and consequently the practices have been diversified. Many fish species are cultured in rice fields. These include high-value species such as snakeskin gourami (*Trichogaster pectoralis*), climbing perch (*A. testudineus*), catfish (*P. hypophthalmus*) and freshwater prawn (*M. rosenbergii*) as well as low value species such as silver barb, tilapia and Indian carps. Silver barb is particularly suited to rice-fish systems as it survives and grows well. Moreover, fish or prawn culture can be alternated with rice cultivation (Wilder and Phuong, 2002).

Inorganic fertilizers are most commonly used in rice-fish systems. In a survey of 262 fish farms in the Mekong Delta, Long (2002) found that the application rates of inorganic fertilizer into the systems were extremely low ranging between 82–105 kg/ha/year. Urea was most commonly used. Organic fertilizers are not widely used in the rice-fish systems. A variety of feeds are used to supplement natural foods and include amongst others rice bran, broken rice, waste vegetable, water spinach and sweet potato leaves. Fish yield depends on whether the fish receive supplemental feed or not and varies from 50–150 kg/ha/year under no feeding conditions to over 300 kg/ha/year with supplementary feeding.

2.1.4 Giant freshwater prawn (Macrobrachium rosenbergii)

Existing culture systems of *M. rosenbergii* include improved-extensive culture in rice fields, and semi-intensive and/or intensive culture in ponds, orchard canals and pens.

Pond culture

Giant freshwater prawn are fed on pellets and farm-made feeds. Farm-made feeds consist of trash fish, golden snail, rice bran and other ingredients. Trash fish is only incorporated into the feed when golden snails are scarce. During the first month the prawns are fed exclusively on pellets and for the remaining five months they are normally fed a combination of pellets (40 percent) and farm-made feed (60 percent). The ration decreases with age from around 30 percent of pond biomass for the first week after stocking to around 8–10 percent between weeks 9 and 24 and the prawns are fed 4 times per day and consumption is monitored (Long, 2003). Yields vary from 500–1 200 kg/ha/cycle (MOFI, 1999).

Rice-prawn integrated system

Besides the Mekong Delta where rice-prawn farming systems are common, farmers in northern Viet Nam have also recently adopted this practice (Trang, Thanh and Phuong, 2004). Rice fields are usually fertilized to stimulate the growth of the rice and of natural food. Animal manures and green fodder (wet composting) are widely used as fertilizers. Animal manures are only applied after composting at a rate of 20–30 kg/100 m^2 and green fodders are applied at the same rate. No supplemental feeds are provided to the rice-prawn systems in northern Viet Nam. By contrast, farmers in the Mekong Delta usually provide supplementary feed in the form of pellets and farm-made feeds. Farm-made feeds and feeding schedules are identical to those described in the previous section and yield varies from 300–500 kg/ha/crop. A recent study in Can Tho showed that farmers can obtain up to 600 kg/ha of prawns in the winter-rice crop by feeding a 9:1 mixture of golden snail and pellets (Hien, 2004).

Pen culture of prawn

Pens range in size between 100 and 900 m^2 and prawns are usually stocked in June at an average density of 62/m^2. Pen culture is practiced on a multiple harvest strategy to maximize productivity and prawns are harvested every 2–4 months starting from the 4th month after the initial stocking. Harvesting lasts until late December or January. Average prawn yield is 0.52 kg/m^2/year, Farm-made feeds are made from locally available ingredients such as snails, mud crab, trash fish, rice, coconut meal and cassava roots and fed twice a day at 22 percent of body weight per day (Son, Yi and Phuong, 2005).

2.1.5 Cage culture of fish

A variety of species are farmed in cages. Grass carp are produced in small cages along rivers or in reservoirs in northern Viet Nam, the central highlands and southeastern Viet Nam. Feed consists of locally available grasses. FCR is as high as 40:1 on a wet weight basis. In intensive cage culture, grass carp can be fed on other feeds such as paddy sprouts, sweet potato, cassava and cassava leaves.

Giant snakehead, *C. micropeltes* is preferred by consumers and is cultured only in cages, while snakehead murrel (*C. striata)* is cultured only in ponds. Chopped trash fish is the sole feed for these fish and FCR ranges from 4.5–5:1. The recent proliferation of snakehead culture has become problematic as the capture of juveniles is affecting the conservation status of the species and of wetland biomes.

Cage culture of red tilapia is a recent initiative (1999), particularly in the peri-urban areas of Ho Chi Minh City and other cities. Red tilapia production in peri-urban areas of Ho Chi Minh City has increased from 300 tonnes in 2000 to 4 200 tonnes in 2004 and this is a substantial proportion of national red tilapia production, which in 2004 reached 15 000–20 000 tonnes. Farmers raise fingerlings in earthen ponds until they reach 50–100 g and then transfer them to cages, which vary in size from 60–120 m^3. Commercially formulated pellets are the main feed. Protein levels in the feeds range from 35–40 percent for fingerlings and 22–25 percent for growth-out. The fish are reared for 4–5 months to a marketable size of 0.6–1.0 kg. The fish are fed 3–4 times per day, following the feeding schedule of the manufacturer. FCR's using formulated feeds range between 2.2–2.5:1. Farm-made feeds are rarely used in tilapia cage culture (Hung, Truc and Huy, 2007). Yields are high and range from 100–150 kg/m^3/year.

TABLE 6
Technical parameters for *Pangasius* cage culture

Parameters	Description
Unit size (m^3)	96–576
Species cultured	*P. hypophthalmus, P. bocourti*
Feed used	Farm-made feed in combination with pellets in early months of rearing
Feeding strategy	2–3 times/day, 3–5 % body weight/day
Yield (kg/m^3/5–7 month cycle)	150–200

Source: Hung, Truc and Huy (2007)

The Mekong Delta is the main area for cage culture of pangasiid catfish, particularly *P. hypophthalmus*, *P. bocourti* and *P. conchophilus*. A detailed comparative account of pangasiid cage and pond culture in the Mekong Delta is provided by Hung, Truc and Huy (2007). Table 6 summarizes some technical parameters of pangasiid cage culture.

2.1.6 Intensive pond culture of fish

Pond culture of carnivorous fish is a common practice in Viet Nam. Snakehead, *Chana striata* is one of the main carnivorous species, which is intensively cultured in ponds in Viet Nam. Farm-made feeds are preferred and pelleted feeds are rarely used. Farm-made feeds with a protein content of at least 40 percent are made from trash fish, snails, small shrimps and chopped squid as protein sources and mixed with rice bran, broken rice or corn bran as well as vitamins and minerals to form moist pellets. The fish are fed twice a day on a ration of 4–5 percent biomass per day. At present, the practice is heavily dependent on trash fish.

Hybrid clariid catfish are raised mainly with restaurant wastes and animal manure. As mentioned previously the fish is commonly used in integrated livestock systems as they can effectively utilize livestock waste and can survive in poor water quality. Ground and mixed slaughterhouse waste such as poultry bones and intestines, livestock bones, restaurant waste, shrimp head waste, fish processing waste can also be used for hybrid catfish.

Pangasiid pond culture has developed rapidly in recent years, particularly since the successful artificial breeding of tra catfish (*P. hypophthalmus*). The high cost of cage culture has also contributed to the development of pond culture. Hung, Truc and Huy (2007) provide a detailed comparative account of pangasiid pond, pen and cage culture (see also Phuong, Minh and Tuan, 2004). Table 7 summarizes some of the comparative detail.

Giant gourami (*Osphronemus goramy*) is cultured mostly in ponds in southern Viet Nam and fed on aquatic or terrestrial plants. Even though the fish is classified as a herbivore, it readily consumes mixed farm-made feeds and pellets. By using pellets the production cycle can be reduced from 15–18 months to 8–10 months. The fish are grown mainly in peri-urban areas to supply restaurants and middle-class markets (Hung, 2004) and pond culture of gourami is often combined with morning glory culture (Huy, 2003).

TABLE 7
Technical description of pangasiid pond and pen culture in the Mekong delta

Description	Pond culture	Pen culture
Pond size	0.3–1.0 ha	0.3–0.5 ha
Culture period (month)	6.25±0.87	5.6±0.8
Stocking density (nos./m^2)	20.5±10.0 (15–35)	34.8±8.1
Feeds	farm-made feeds & pellets	farm-made feeds & pellets
Survival rate (%)	94.0±2.20	82.6±4.0
Productivity (tonnes/ha/crop)	150–-350	345±149

Source: Phuong, Minh and Tuan (2004)

2.2 Coastal aquaculture systems

2.2.1 Pond culture of tiger shrimp

Shrimp culture in central Viet Nam is mainly intensive, whereas in the north and in southern Viet Nam it continues to range from extensive to intensive. The different systems require different feeding strategies and feeds.

Extensive system

Extensive shrimp farming is a traditional farming practice in the Mekong Delta and other coastal provinces. In extensive systems water is exchanged tidally with the inflow bringing natural seed and feed to the culture ponds. Twice a month during the low spring tide, shrimp and fish are harvested as they move down with the water current to the sea. Feeding is not practiced in extensive systems and shrimp rely on naturally available foods. Until about 10 to 15 years ago natural seed abundance of *Penaeus merguensis and P. indicus* was sufficiently high to supply the ponds with juveniles. Recently farmers have had to stock tiger shrimp PLs to improve their yields due to a decline of natural seed. This is known as the improved extensive system. The two systems occupy a large proportion of shrimp culture surface area in Viet Nam and particularly in the Mekong Delta. In 2003, extensive and improved extensive systems accounted for 68 percent and 27 percent of the shrimp farming surface area in the Mekong delta, respectively (Phuong, Minh and Tuan, 2004).

Semi-intensive and intensive systems

In semi intensive systems the natural food is supplemented with trash fish, small shrimp (*Acetes sp*.) and low price shrimp pellets. Stocking density ranges form 5–10/m^2. Aeration is not used. The systems may be operated on shrimp/rice rotation basis or integrated with mangroves. There are 20 500 ha of semi-intensive shrimp farms in the Mekong delta (MOFI, 2003).

In the intensive systems, shrimp are stocked at 20–50 Post Larvae (PL) per m^2. The system requires a high level of maintenance and management with respect to feeding, water quality control, the controlled use of antibiotics and aeration. Though most farmers use commercially formulated shrimp feeds in these systems, some still follow traditional methods of improving yields by using fertilizer to stimulate plankton growth and adding trash fish. The total surface area under intensive culture in 2003 was 15 534 ha (MOFI, 2004). The main species in the Mekong Delta is tiger shrimp, while Pacific white shrimp *L.vannamei* has now been introduced to farms in central Viet Nam. Stocking densities for white shrimp (95 PL/m^2) are much higher than for tiger shrimp (18 PL/m^2).

Formulated feeds are most often used in intensive systems, though some farmers combine formulated and farm-made feeds during the final days of the production cycle. Farm-made feeds include cooked trash fish, small shrimp and molluscs. A study in Quang Ngai province of central Viet Nam shows that 30 percent of farmers still use farm-made feeds in intensive tiger shrimp culture, but not for white shrimp (Nhan, 2005).

Farmers use feeding trays (2–4 trays per 4 000–5 000 m^2 pond) to monitor consumption and to adjust the ration. Pellets are broadcast over the pond surface 2 to 3 times per day using a boat or floating raft. All feed producers provide feeding tables to avoid over or under feeding. Table 8 is an example of a recommended feeding strategy. Daily feed is adjusted according to shrimp size and the remaining portion of feed on the feeding tray. Under good management FCRs for commercially formulated feeds range from 1.3–1.5:1. In poorly managed systems FCR can be as high as 2.5:1. Under intensive culture conditions yields of up to 7 tonnes/ha/crop can be attained.

TABLE 8
Manufacturer recommended feeding schedules for intensive shrimp culture using formulated feeds

Stage	Shrimp size (g)	Feeding rate[1]	% feed distributed on feeding trays	Feeding tray monitoring intervals (hrs)
PL_{20}–PL_{27}	<0.2	1.0–1.5 kg/90 000 post larvae per day	NA	NA
PL_{28}–PL_{35}	0.2–0.6	1.5–2 kg/90 000 post larvae per day	NA	NA
PL_{36}–PL_{45}	0.6–1.5	6 – 6.5	2	3
PL_{46}–PL_{55}	1.5–5.0	5.5	2.4	2.5
PL_{56}–PL_{75}	5.0–10.0	4.5	2.8	2.5
PL_{76}–PL_{95}	10.0–20.0	3.8	3.0	2
>PL_{95}	>20.0	3.5	3.3	2

[1] Percent body weight per day unless otherwise indicated; NA = not applicable

Source: Ocialis Feed Company, Viet Nam (pers. com.)

2.2.2 Rice-shrimp alternating system

Alternating rice with shrimp culture is typical in many places in the Mekong Delta. The system was developed because of saltwater intrusion into rice fields during the dry season. During this period shrimp are stocked into the paddy fields and reared under improved extensive or semi-intensive conditions. Some output data from these systems is provided in Table 9.

TABLE 9
Some technical and economical parameters of alternating rice-shrimp culture in the Mekong Delta

Parameters	Data
Pond area (ha)	1–2
Water surface (%)	25–30%
Water level in rice field	30–50 cm
Seed	Hatchery produced seed (PL_{15})
Stocking density (piece/m²)	2–-55 PLs/m²
Cropping season	January – May
Feed	Pellet and farm-made feeds
Fertilization	Lime and fertilizer
Average survival rate	10–33%
Production (kg/ha/year)	300–450
Total cost (VND million/ha/crop)	10–15
Total revenue (VND million/ha/crop)	30–45
Benefit-/-cost ratio	2.5–3.0

US$1.00 = VND 15 800

Source: Phuong, Minh and Tuan (2004)

In these systems fertilizers are only applied when phytoplankton does not develop naturally. Farmers prefer chicken manure that is packed in bags and immersed. Inorganic fertilizer (NPK (nitrogen, phosphorus and potassium) 20:20:15 and urea (46 percent) at a 4:1 ratio) is only used when organic fertilizers are unavailable and is applied at 3–5 kg/1 000m².

The price and nutritive quality of feeds used in these systems is lower than those used in intensive systems. Several manufacturers produce specific feeds for rice-shrimp systems. Farmers usually use commercially formulated feed in the first month where after they use farm-made feeds. A recent study has found that the use of farm-made feeds in these systems is wasteful and environmentally not sustainable and recommends that formulated feeds only be used when natural food is limiting (Burford *et al.*, 2004). Shrimps are fed 3–4 times per day and the ration is adjusted according to shrimp size and appetite (Preston and Clayton, 2004).

2.2.3 Marine fish and lobster

Marine fish and lobster are mainly cultured in floating cages in central and northern Viet Nam. Besides cage culture, marine fish and mud crab are also cultured in earthen ponds

Lobster

The preferred feeds for lobster cage culture are molluscs, crustaceans and trash fish (preferably red big-eye, pony fish and lizardfish). FCRs range from 28–29:1. The feeding regime is size dependent. Small lobsters are fed 3–4 times per day with a higher feed amount in the evening. Trash fish is chopped into small pieces, while molluscs are removed from their shells. At 400g and larger they are fed twice daily and feeding intensity is substantially increased before moulting. During the last few months the proportion of molluscs and crustacean is increased, while trash fish is decreased (Tuan, 2003). Feeding practices may vary from one place to another. For example, Edwards, Tuan and Allan (2004) report that lobsters in some areas are fed once per day and farmers alternate between trash fish, snails, clams and small crustaceans on a daily basis to maintain optimum food intake. Lobsters also adapt well to formulated feeds, though water stability and price largely preclude the use of pellets (Edwards, Tuan and Allan, 2004). Cages vary in size from 3–50 m^2 (bottom area) and 2–3 m in depth with a submerged depth of 1–1.5 m (Tuan, 2003).

Grouper and cobia culture

Grouper are cultured in cages and in earthen ponds. Stocking density in cages may be as high as 25 fish/m^3 but can be adjusted accordingly to size of the seed. The main feeds are trash fish, shrimp and crabs. Despite its high price (VND 3 000–10 000/kg), the preferred trash fish for grouper is anchovy. If anchovy is in short supply farmers use pony fish at around half the price. The fish are fed twice a day at dawn and dusk on a daily ration of 3–10 percent fish biomass. Trash fish is used whole or chopped according to the mouth size of the fish. Trash fish is sometimes boosted with a vitamin and mineral premix at 0.5 percent of feed weight. Decayed or rotten trash fish is not used for grouper culture. Recent work by Edwards, Tuan and Allan (2004) has shown that trash fish for grouper as well as cobia is the most cost effective, though MOFI is concerned about the level of pollution caused by the use of this food in grouper and cobia culture. Presently, grouper and cobia culture is entirely dependent on trash fish. The reduced availability of this commodity has now forced many farmers to reduce their feeding frequency to once every four days. Interestingly, growth rate has not been significantly affected and this practice reduces the impact of cage culture on the environment (Thanh, 2005).

Pond culture of grouper is a recent initiative and investment costs are lower than cage culture. The FCR of grouper in ponds (4.3:1) is lower than in cages (Trai and Hambrey, 1998).

3. REVIEW OF THE AQUAFEED INDUSTRY

Aquafeed production in Viet Nam started in 1998 when several animal feed manufacturers recognized the opportunities. The domestic animal feed industry is well established. Currently only shrimp and pangasiid catfish feeds are made (Hung, 2006). The aquafeed industry is reviewed in the context of its present status, opportunities and constraints to support the sustainable development of aquaculture.

3.1 Animal feed Industry

Commercial animal feed production has grown at an annual rate of 10–13 percent. In 2003 Viet Nam produced 3.8 million tonnes of animal feed, of which 70 percent comprised complete feeds and 30 percent of concentrates (which the farmers mix with on-farm ingredients). Current production does not meet the domestic demand (Table 10). The industry relies heavily on imported feed ingredients, including soybean meal, corn, fishmeal, meat and bone meal, rice and wheat bran and feed pre-mixes and vitamins (Huong, 2004).

According to MARD there were 182 animal feed and premix manufacturers operating in Viet Nam in 2003. Of these 138 are fully fledged animal feed mills that produce complete feeds as well as feed concentrates. The total production capacity of the animal feedmills is estimated at 5 million tonnes per annum, which falls short of the demand (Table 10). Fifteen of the 138 feedmills are either wholly owned subsidiaries of foreign companies or are joint ventures and these companies hold more than 50 percent of the animal feed production capacity in Viet Nam. Key companies include Proconco a Viet Nam - French joint venture), CP Group of Thailand, Cargill of the United States of America, Uni President of Taiwan Province of China and the Cheil Jedang Group of South Korea (Huong, 2004).

Because of the rapidly increasing demand for aquafeeds, animal feed manufacturers have shifted their production lines to produce aquafeeds mainly for shrimp and pangasiid catfish.

TABLE 10
Animal feed requirements and production in 2000-2002 (thousand tonnes)

Year	2000	2001	2002
National animal feed requirement	8 200	8 500	8 900
Total animal feed production	2 700	3 000	3 400
Complete feed	1 700	1 950	2 400
Feed concentrate	330	350	340

Source: Ministry of Agriculture and Rural Development, MARD (pers. com.)

3.2 Shrimp feeds

The shrimp feed industry is in its infancy. Activities began in 1998 with an annual production of 10 000 tonnes per year. The current demand for commercial shrimp feeds in Viet Nam is about 150 000–200 000 tonnes per year. Although the bulk of the demand can theoretically be met by domestic production, approximately 3–5 percent still has to be imported (Hung, 2006).

There are 36 aquafeed-mills in Viet Nam, 23 of which produce shrimp feed. Five multinational companies each with an installed capacity of 20 000–40 000 tonnes per annum, dominate shrimp feed production in the country. In addition to the larger companies, there are about 10 smaller, locally owned companies that manufacture shrimp feeds. These feed mills have an installed capacity of 5 000–10 000 tonnes per year. However, many of them are not adequately equipped to produce good quality feed. Most of the local companies simply adapted their livestock feed equipment to produce shrimp feed and found that such modifications seldom worked well. As a result, many are now planning to install dedicated shrimp feed manufacturing equipment. The main producers of shrimp feed, their location and capacity are listed in Table 11.

The total capacity of shrimp feedmills in Viet Nam is in the range of 300 000–400 000 tonnes per annum, which currently exceeds demand. Despite the over-capacity, further growth in the country's shrimp feed industry is expected due to following reasons (Hung, 2006):

- the seasonal nature of shrimp farming, produces a peak in demand during the summer months that exceeds installed capacity. Stronger companies with high market share are expanding their feedmill capacity; and
- the intensive shrimp farming sector, though occupying less than 10 percent of national shrimp pond surface area consumes 80–90 percent of formulated feeds. Further intensification of shrimp farming in the country provides enormous scope for growth of the feed industry.

TABLE 11
List of main shrimp feed producers in Viet Nam

Company	Ownership	Location	Capacity (tonnes/year)	Year of commencement
C J Vina Agri	South Korea	Long An	12 000	2003
Ocialis	France	Binh Duong	10 000	2003
Asia Hawaii	Joint venture (VN-USA)	Phu Yen	20 000	2002
Uni-President	Taiwan Province of China	Binh Duong	60 000	2001
Uni-Long	Taiwan Province of China	Nha Trang	20 000	2000
Grobest	Taiwan Province of China	Dong Nai	25 000	2001
CP group	Thailand	Dong Nai	30 000–40 000	2001
Tom Boy	Taiwan Province of Chin	HCM city	30 000	2002
Cargill	USA	Dong Nai	10 000	2001
Proconco	Joint venture (VN-France)	Can Tho	12 000	2000
Cataco	Viet Nam	Can Tho	12 000	2003
Dabasco	Viet Nam	Can Tho	20 000	2002
Seaprodex	Viet Nam	Da Nang	15 000	1990

Source: Serene and Merican (2004)

TABLE 12
Nutrient composition of commercial shrimp feed (% dry matter basis)

Stage	Moisture	Crude protein	Crude lipid	Crude fibre	Ash	Calcium	Phosphorus
Post larvae	<11	>43	>5	<3	<16	>2.5	>1.5
Starter	<11	>41	>6	<3	<16	>2.5	>1.5
Grower	<11	>38	>6	<3	<16	>2.5	>1.5
Finisher	<11	>36	>6	<3	<16	>2.5	>1.5

Source: Ocialis Feed Company, Viet Nam (pers. com.)

Most shrimp feedmills in Viet Nam are located in the vicinity of Ho Chi Minh City. Its port and accessibility to markets provide distinct advantages to feed manufacturers. Almost all major shrimp feed ingredients including soybean meal, fishmeal, flour, fish oil and feed additives are imported. Besides the average import duty of 10 percent, all ingredients and feed additives carry value-added tax (VAT) at five percent, except for soybean meal.

In 2004, the Ministry of Fisheries published a quality standard for shrimp feed (28 TCN 102: 2004) that obligates feedmills to comply with certain minimum standards (Appendix A.1.). According to the standard, crude protein content of the manufactured feeds should be 35 percent for grow-out shrimp (>20g) and up to 42 percent for beginner feeds (0.01–0.20 g). Gross energy should be at least 3 000 cal/kg^{-} for grow-out and 3 400 cal/kg for beginner feeds. Other nutrients in formulated feed such as crude lipids, calcium, phosphorus, fibre, mineral, lysine and methionine and aflatoxin are also standardized. There are about 5–6 types of feeds that are produced for different stages of tiger shrimp. The nutrient composition of the various products does not differ much among producers. Table 12 is an example of the general nutrient composition of shrimp feeds.

Feed is distributed through an elaborate network of dealers and sub-dealers throughout the country. Each company sets up its own distribution channel to cover markets in coastal provinces from the south to the north of Viet Nam. The average price of grow-out feed is US$1.00 per kg and does not vary much among companies. Dealers typically provide the feed on a cash-only basis during the first two months of a crop, where after credit can be extended for the remaining culture period depending on growth and survival.

3.3 Fish feeds

Formulated pellets are used mainly in *Pangasius* catfish and red tilapia. However, trash fish still remains as one of the major feed components for all omnivorous and carnivorous fish species.

3.3.1 Trash fish

Trash fish is traditionally used to feed freshwater and marine carnivorous fish and lobsters. Trash fish mainly comprises low value species from the marine and inland capture fisheries. The rapid development of carnivorous fish culture has resulted in an imbalance between supply and demand and this has led to substantial price increases

TABLE 13
An estimation of trash fish used for inland and marine fish culture in Viet Nam

Species	Production (tonnes)	%of trash fish use	FCR	Moist/wet feed (tonnes)	Trash fish (tonnes)	
					Min	Max
Pangasius catfish	180 000	80	2.50	360 000	64 800	180 000
Marine shrimp	160 000	38	4.74	287 280	71 820	143 640
Marine fish	2 000	100	5.90	11 800	11 800	11 800
Lobster	1 000	100	28.00	28 000	28 000	28 000
Total				**6 870 801**	**176 420**	**363 440**

Source: Edwards, Tuan and Allan (2004) in recent years. There are no official statistics on trash fish consumption by the aquaculture sector. However, Edwards, Tuan and Allan (2004) estimated (Table 13) that between 64 800–180 000 and 72 000–144 000 tonnes of trash fish is used for inland and coastal aquaculture, respectively and that total consumption of the aquaculture sector in Viet Nam was between 177 000–364 000 tonnes per annum.

It is likely that Edwards, Tuan and Allan (2004) underestimated trash fish consumption because they did not take full account of snakehead culture in the Mekong Delta. There have been many Research and Development (R&D) attempts to promote the use of alternative feeds for carnivores but results have not been widely applied in practice.

3.3.2 **Pangasius** *catfish feed*

Viet Nam is the largest producer of pangasiid catfish in the world. The national production in 2004 was about 260 000–300 000 tonnes (MOFI, 2004). Basa catfish (*P. bocourti*) and tra catfish (*P. hypophthalmus*) are the dominant culture species in Viet Nam. Besides farm-made feeds, formulated feeds are increasingly being used in catfish production. Although the cost of manufactured feeds is higher than that of farm-made feeds, farmers are of the opinion that the quality of fish is improved when manufactured feeds are used. Contrary to commercial shrimp feeds, catfish feeds are formulated using mostly local ingredients such as rice bran, cassava meal, soybean meal, local fishmeal and feed additives. All manufactured feeds are extruded. The leading catfish feed producers at present are Proconco, Cargill, Uni President and Green Feed. Collectively, these companies have an installed capacity of 80 000–100 000 tonnes per year (Table 14) (Hung, 2006).

Local companies such as Afiex, Cataco and Vinh Tuong also manufacture significant volumes of catfish feeds. Collectively, these companies have an installed capacity of 30 000–50 000 tonnes per year. There are no official data for commercial catfish feed production. However, based on catfish production data it is estimated that some 300 000–400 000 tonnes of commercial catfish feed was produced in 2004.

Manufactured catfish feeds also have to meet feed quality standards as assigned by the Ministry of Fisheries (28 TCN 188:2004, see Appendix A.2.), according to which the crude protein content in formulated feeds should be at least 18 percent for grow out (500 g) and up to 40 percent for fingerlings (1–5 g). Gross energy should be in the range of 1 500 cal/g for fish size of 500 g and up to 3 300 cal/g for fingerlings (1–5 g). Other nutrients including lipid, fibre, ash, calcium, phosphorus, lysine and methionine are also standardised. Table 15 is an example of the nutrient composition of a commercial catfish feed.

TABLE 14

Annual capacity of catfish feed producers

Feedmill	Location	Annual production capacity (tonnes)
Multinational		
Proconco	Can Tho	100 000–120 000
Cargill	Dong Nai	60 000–80 000
Uni President	Binh Duong	60 000–80 000
Green Feed	Long An	60 000–80 000
Woosung	Dong Nai	60 000–80 000
Tan Sanh	Mekong Delta	40 000–50 000
Local		
Viet Thang	Mekong Delta	40 000–50 000
Afiex	Mekong Delta	30 000–50 000
Cataco	Mekong Delta	30 000–50 000
My Tuong	Mekong Delta	20 000–30 000

Source: Hung (2006)

TABLE 15

Nutrient composition of a commercial formulated feed for *Pangasius* catfish (percent dry matter basis, unless otherwise indicated)

Feed types	Crude protein (minimum)	Crude lipid minimum	Calcium	Crude fibre	Phosphorus	Moisture	ME (cal/kg)	Lysine	Methionine
6106	35	3.0	1.0–3.0	6	0.95	11.0	2 500	1.50	0.85
6116	32	3.0	1.0–3.0	6	0.95	11.0	2 600	1.45	0.70
6326	28	2.5	1.0–3.1	6	1.00	11.0	2 000	1.30	0.65
6336	25	2.2	0.8–2.5	7	1.00	11.0	2 000	1.00	0.50
6346	22	2.2	0.8–2.5	7	1.00	11.0	2 000	0.80	0.45
6356	20	2.2	0.8–2.5	7	1.00	11.0	2 000	0.60	0.50

Source: Green Feed Company (pers. com.)

TABLE 16
Nutrient composition of commercially formulated tilapia feed (% dry matter basis)

Fish stage/size (g)	Feed type/Ssize (mm)	Moisture	Crude protein	Crude lipid	Crude fibre	Ash
Fingerlings	Crumbles	11	40	5	4	10
5–20	Pellet (1.5)	11	40	5	4	10
20–200	Pellet (2.0)	11	30	6	4	10
200–400	Pellet (3.0)	11	30	6	4	10
400–600	Pellet (5.0)	11	22	5	6	12
600–1000	Pellet (7.0)	11	22	5	6	12

Source: Cargill Company (pers. com.)

The average price of the feeds is around US$0.35/kg for starter feeds with 30 percent crude protein and US$0.25/kg for grower feeds (18–20 percent crude protein). Typical FCRs are around 1.5 and 2.0:1 in ponds and cages, respectively.

3.3.3 Tilapia feed

Because of the integrated nature of tilapia farming in Viet Nam the use of formulated feeds is unprofitable. Several previous attempts to culture GIFT (genetically modified farm tilapia) tilapia in cages using formulated feeds have not yielded good economic results, though recent work by the Research Institute for Aquaculture (RIA) No. 1 suggests otherwise. However, the use of formulated pellets for cage and tank farming of red tilapia is a viable proposition. In the past farmers simply used formulated catfish pellets, but because of increasing demand for a tilapia formulation, manufacturers have recently introduced a feed to the market. There is no official data for tilapia feed consumption but based on red tilapia production in Viet Nam, it is estimated that there would be a current demand of around 50 000–60 000 tonnes of tilapia feed per annum.

In 2004, MOFI published a quality standard for formulated tilapia feeds (28 TCN 189: 2004, Appendix A.3.). Crude protein content should be in the range of 20 percent for grow-out (500 g fish size) to 40 percent in crumble feeds for fingerlings (5 g). Gross energy should be at least 2700 cal/g for growth out and up to 3200 cal/g for fingerling feed. Other nutrients are also standardized. Table 16 provides an example of the nutrient composition of tilapia feeds.

3.3.4 Marine fish feed

Grouper, cobia, sea bream, snapper are currently the four main marine fish cultured in Viet Nam. As outlined above and mainly for economic reasons trash fish remains the feed of choice (Edwards, Tuan and Allan, 2004). Formulated feeds, imported from Taiwan Province of China are currently being tested to replace trash fish. Two feed companies (Uni President and CP Group) have attempted to develop a local formulation to replace trash fish in marine fish farming (Orachunwong , Thammasart and Lohawatanakul, 2005).

4. FERTILIZERS, FEED INGREDIENTS AND FEEDS IN AQUACULTURE

In semi-intensive and intensive fish farming systems, nutrient inputs including feeds and fertilizers are essential for fish production. This section of the review focuses on fertilizer use and supply and feed ingredient composition, availability and supply.

4.1 Fertilizers

4.1.1 Inorganic fertilizers

Viet Nam imports most of its inorganic fertilizers for rice farming and other crops and supply is rarely limited. However, the use of inorganic fertilizers has not yet become a common practice in aquaculture in Viet Nam. Fertilizers are mainly applied for intermediate stimulation of phytoplankton growth during the nursery period.

The most commonly used inorganic fertilizers are Urea, NPK and DAP (di-ammonium-phosphate).

Urea is the most popular fertilizer applied to shrimp ponds and is applied at a loading rate of 20–30 kg/5 000 m^2 to boost phytoplankton growth in the initial 15–20 days, during which the post larvae cannot feed on pelleted feed. The most common NPK formulation used is 18:46:0, while di-ammonium-phosphate (DAP) (40 percent P_2O_5 and 18 percent N) is employed in freshwater nursery ponds and intensive shrimp ponds to stimulate intermediate growth of algae and phytoplankton.

TABLE 17
Nutrient content of common animal manures used in aquaculture in Viet Nam

Manure	Percent (fresh weight basis)			
	Moisture	N	P_2O_5	K_2O
Pig	82.0	0.8	0.4	0.3
Cattle	83.1	0.3	0.2	1.0
Horse	75.7	0.4	0.4	0.4
Chicken	56.0	1.6	0.5	0.9
Duck	56.0	1.0	1.4	0.6

Source: Dat (2002)

TABLE 18
Composition of common green fodders used as fertilizers in Viet Nam

Plants	Percent (dry matter basis)	
	N	P_2O_5
Back bean	1.7	0.3
Water hyacinth	4.8	0.6
Duck weed	2.8	0.4

Source: Dat (2002)

4.1.2 Organic fertilizers

The types of organic fertilizer and application rates vary and are dependent on the system, species and farmer habits. Farmers apply various organic fertilizers for pond preparation and or during the nursing stage. Sewerage fed aquaculture systems, particularly for the rearing of red tilapia fry and fingerlings, are popular in Ho Chi Minh City and Ha Noi. However, there are various factors, such as the rapid rate of urbanization, land availability and consumer demands, that presently limit the use of sewerage as a fertilizer source.

Animal manures

As mentioned earlier, animal manures are frequently used in integrated systems to maximize the use of on-farm resources. Application rates are highly variable because farmers are generally not well informed. The general recommended application rate is 25–30 kg/100 m^2 as the primary nutrient base for the development of natural foods in polyculture ponds.

The nutrient content of different animal manures used in aquaculture are shown in Table 17. Chicken, pig and duck manures have the highest N and P_2O_5 content and hence are most frequently applied in aquaculture systems.

The direct application of manure to fish ponds is not a common practice in Viet Nam due to competition with crop farming. However, many farmers construct a pigsty or chicken house over the fishponds or in close proximity to their ponds. It has been found that 2–3 pigs are adequate to fertilize a fishpond area of 500–1 000 m^2.

Green fodder fertilizer

Besides animal manures, some green fodders are also composted to provide pond nutrients. Common green fodders that are used as fertilizers are listed in Table 18. The fodder is placed in a crib in the corner of a pond and the nutrients released stimulate natural productivity. This type of fertilization is usually practiced in small-ponds under polyculture conditions and is most commonly used in upland areas in the central highlands and in southeastern Viet Nam.

4.2 Feed Ingredients

4.2.1 Rice and rice by-products

The conversion rate of paddy rice into its by-products is 64 percent rice, 10 percent rice bran and 6 percent broken rice. The national yearly production of paddy is about 33–34 million tonnes (MARD). Rice and broken rice is mainly used for human

TABLE 19
Annual production of paddy, rice bran and broken rice during 1998-2002

Year	1998	1999	2000	2001	2002
	Production (million tonnes)				
Rice paddy	29.15	31.39	32.53	32.98	33.54
Rice bran	2.91	3.14	3.25	3.30	3.35
Broken rice	1.75	1.88	1.95	1.98	2.01

Source: Ministry of Agriculture and Rural Development, MARD (pers. com.)

TABLE 20
Estimation of rice bran use in aquafeeds for catfish (tonnes)

Feed types	Production	% rice bran		Rice bran used in aquafeeds	
		Min	Max	Min	Max
Formulated feeds	300 000	20	50	60 000	150 000
Farm-made feeds	500 000	40	70	200 000	350 000
Tilapia feeds	50 000	20	40	10 000	20 000
Total				**270 000**	**520 000**

consumption, while rice bran and a small proportion of broken rice are used for animal feed. These by-products are indispensable ingredients in formulated and farm-made feeds for tilapia and *pangasiid* catfish feeds but is rarely used in shrimp feed due to its high fibre content. In 2002, the annual production of rice bran and broken rice in Viet Nam was 3.3–3.5 million and 2.0–2.1 million tonnes, respectively (Table 19).

The inclusion rate of rice bran in formulated catfish and tilapia feeds varies from 20–50 percent, depending on the growth stage. In farm-made feeds, rice bran is used at inclusion rates of 40–70 percent (Phuong, Minh and Tuan, 2004). There are no official data of rice bran consumption by aquaculture. An estimation based on fish production, average FCRs and average inclusion rates is provided in Table 20. The data suggest that the aquafeed industry annually needs 300 000–500 000 tonnes of rice bran. According to the above estimate, domestic rice production can supply the demand of both the animal and aquafeed industries.

TABLE 21
Nutrient composition (% as fed basis) of rice bran and defatted rice bran in Viet Nam

Composition	Dry matter	Crude protein	Crude lipid	NFE	Ash	Crude fibre
Rice bran type I	87.6	13.0	12.0	46.4	8.4	7.8
Rice bran type II	90.3	9.8	6.8	40.1	15.1	18.6
Rice bran type III	89.7	7.6	5.0	38.9	14.9	23.3
Defatted rice bran	89.0	14.9	3.6	47.6	10.4	11.2

Source: NIAH (1995)

There are three types of rice bran in Viet Nam. Type II and III have a low protein content and are not suitable for extruded feeds due to a high fibre content (Table 21). However, they can be used for farm-made feeds. On-farm storage of rice bran is difficult because of the high lipid and moisture content and this affects feed quality. Feedmills usually dry and store large volumes in silos.

De-fatted rice bran (DRB) has a higher protein but lower lipid content than other brans and is therefore commonly used in animal feed.

4.2.2 Wheat flour and wheat bran

Viet Nam imports wheat flour and wheat by-products for human consumption as well as for the animal and aquafeed industries. Some 868 000 tonnes of wheat and by-products were imported in 2004. Shrimp feeds require about 10–15 percent of wheat flour as a binding agent and an energy source. Wheat gluten is also used in shrimp feed while wheat bran is incorporated into catfish feeds.

4.2.3 Maize and maize by-products

Maize and its by-products, including maize bran, maize gluten and maize starch are important components in animal feeds, especially for the poultry feed industry. Domestic maize production does not meet demand and the shortfall is imported. The inclusion rate of maize in aquafeeds varies depending on the kind of product. It can be as high as 35 percent for maize grain meal and 20 percent for maize bran in omnivorous fish feeds (Hertrampf and Pascual, 2000).

However, maize and maize by-products are seldom used in commercial and or farm-made aquafeeds in Viet Nam. The high astaxanthin and canthaxanthin content in maize meal and bran discolours the fish fillet in pangasiid and clariid catfish. Moreover, the higher price of maize meal and bran in comparison to broken rice and rice bran has restricted the use of maize products in aquafeeds.

4.2.4 Cassava and cassava meal

Cassava is not a staple food in Viet Nam. It is used mainly for animal feed and for industrial purposes. In 2003 Viet Nam produced some 5.23 million tonnes. There is no official data on cassava usage in animal feeds. Cassava root is a perishable food and has high moisture content (70 percent) at harvest. Cassava meal is a processed product by sun drying, chopping and grinding the root. Protein content is low (0.9 percent for root and 2.8 percent for meal) and starch content is high. In the central highlands, northeastern and southeastern Viet Nam farmers use fresh cassava root to feed common carp and grass carp in cages and in the Mekong Delta, farmers often use cassava root to feed freshwater prawns.

Cassava meal is used in the manufacture of extruded floating pellets and is included at up to 15 percent. Approximately 30 000–45 000 tonnes of cassava meal is used by the aquafeed industry annually. Cassava is not a common ingredient for traditional farm-made feeds.

4.2.5 Trash fish

Trash fish is that part of the by-catch of marine or inland capture fisheries that is not normally used for human consumption. Traditionally trash fish has been used as a feed for carnivorous as well as omnivorous fish. According to MOFI, trash fish production in 2002 was 200 000 tonnes, comprising 14 percent of total capture fisheries landings. However, Edwards, Tuan and Allan (2004) estimated trash fish production at approximately 0.93 million tonnes in 2001, suggesting that the MOFI underestimated the proportion of trash fish from the capture fisheries.

Trash fish is currently an indispensable feed for carnivorous fish and as mentioned above is also used in farm-made feeds for omnivorous species. Previously, trash fish was very abundant during the flood season in the Mekong Delta and was used for human consumption, manufacture of fish sauce and as a feed for snakehead. Snakehead culture in the Delta has developed to such an extent that farmers now have to use trash fish of marine origin. FCR of trash fish ranges from 4–5 for snakeheads and as high as 12–15:1 for grouper (Trai and Hambrey, 1998). Farm-made feeds contain between 20–30 percent of trash fish and Edwards, Tuan and Allan (2004) estimated that if only 50 percent of *Pangasius* farmers incorporate trash fish into their feeds then some 65 000–180 000 tonnes are used by these farmers alone.

The quality of trash fish is a major concern. Quality declines rapidly as only ice or chilled water is used to preserve trash fish at sea. This is compounded by inadequate on-board storage facilities as the vessels stay at sea for one to four weeks. Edwards, Tuan and Allan, (2004) estimated that between 50 and 60 percent of the total offshore trawler catch goes to waste because of poor storage.

The supply of marine trash fish is highly seasonal, causing major fluctuations in supply and price. During the high fishing season the price ranges between VND 1 500–2 000/kg and during the rough seas season (October to December) the price increases to VND 3 000–5 000/kg. Trash fish availability is considered one of the most serious constraints for aquaculture development in Viet Nam.

4.2.6 Live organisms

Small-scale farmers usually use various live organisms to feed their fish. Similar to other countries, termites, small frogs and golden snails are the most common feed organisms. The most important of these for aquaculture is the golden snail that was introduced into Viet Nam in the 1980s for human consumption and in the hope of developing an export industry. The species has now become a catastrophic pest. With the shell removed the snail has a protein content of 9–11 percent, 0.3–0.7 percent lipids and 3.9–8.3 percent carbohydrate and is used particularly as an ingredient in freshwater prawn and fish feeds. The snails are minced and mixed with rice bran at a ratio of 10 parts snail and 1 part rice bran. Prawn FCRs with this mixed feed ranges from 10–15:1 (Hien, 2004). The price of snails (shell-removed) at VND 1 200–1 500/kg is often cheaper than trash fish at VND 2 500–3 000/kg.

4.2.7 Fish processing waste

Viet Nam has 600 fish processing factories that produce fish fillets, beheaded and shelled shrimp and process molluscs before freezing and packing. A large quantity of processing waste is consequently produced.

It has been estimated that some 30 percent of processed shrimp ends up as waste and that some 60 000–70 000 tonnes of shrimp head waste is produced annually. The product has a protein content of 33.5 percent, 3.5 percent lipids, 26.4 percent minerals (NIAH, 1995). Shrimp head waste is a good source of protein for fish feed but its digestibility is low. It can be used as a direct feed for hybrid clariid and pangasiid catfish or can be sun dried to produce shrimp head meal, which is an essential component in shrimp feed since it is rich in chitin, astaxanthin and attractants. The inclusion rate in shrimp feeds varies between 2–5 percent.

It has been estimated that pangasiid catfish processing waste amounts to around 210 000 tonnes per annum. The waste is processed into various products for human consumption and as well as for animal and fish feeds (particularly for pangasiid catfish). There is an urgent need to evaluate the potential of using a proportion of the waste for the production of fishmeal.

Mollusc processing factories also produce offal, which is sometimes used for the feeding of hybrid clariid and pangasiid catfish. Unfortunately none of the factories process mollusc waste into oil, squid liver meal and other mollusc meal and hence Viet Nam has to import these products for incorporation into shrimp feeds.

4.2.8 Fishmeal

Fishmeal is an essential component of most commercial aquafeeds. Viet Nam produces between 3 000 and 10 000 tonnes of fishmeal and 185 000 tonnes of "fish powder" per annum (Edwards, Tuan and Allan, 2004). Fish powder is made in the traditional manner (drying and grinding). Fishmeal is manufactured mainly form trash fish, spoiled fish and processing waste and hence is of inferior quality to the imported equivalent and sometimes contains high levels of histamine and cadaverine substances (Edwards, Tuan and Allan, 2004). The protein content (Table 22) of local fishmeal varies between 30 and 59.3 percent (NIAH, 1995). Local fishmeal is not used in shrimp feeds.

There are no official data of fishmeal consumption by aquaculture and this had to be estimated based on aquaculture production statistics and inclusion rates in various

TABLE 22
Proximal composition (percent dry matter basis) of fishmeal produced in Viet Nam

Fishmeal type	Crude protein	Crude lipid	Crude fibre	Ash	Ca	P
Fishmeal Ba Hon	57.6	1.0	0.7	15.8	5.2	2.7
Fishmeal Da Nang	45.0	12.0	2.4	29.6	5.0	2.5
Ha Long 45%	45.0	6.4	2.4	27.0	5.0	2.2
Ha Long 50%	50.0	4.3	-	25.1	5.0	2.5
Kien Giang	30.0	6.9	4.2	38.2	8.3	3.2
Fishmeal 60%	59.3	8.2	-	24.2	5.1	2.8

Source: NIAH (1995)

TABLE 23
Estimation of fishmeal use in aquafeeds in Viet Nam

Feed types	Production	% fishmeal		Fishmeal used in aquafeed	
		Min	Max	Min	Max
Shrimp feed	180 000	20	25	36 000	45 000
Catfish feed	300 000	3	5	9 000	15 000
Tilapia feed	50 000	3	5	1 500	2 500
Total				**46 500**	**62 500**

feeds (Table 23). The analysis suggest that some 45 000 to 60 000 tonnes of fishmeal were required for aquafeeds in 2003. This estimate is not much different to that of Edwards, Tuan and Allan (2004) who estimated that Viet Nam used a minimum of 30 000 to a maximum of 105 000 tonnes of fishmeal for aquafeeds in 2001/2. Given the production of local fishmeal suggest that at least 90 percent of fishmeal used in aquafeeds is imported. Fishmeal imports to Viet Nam have increased from 14 000 tonnes in 1999 to 60 000 tonnes in 2003. Edwards, Tuan and Allan (2004) predict that Viet Nam will require at least 150 000 to 200 000 tonnes of fishmeal per annum to sustain the current growth rate of aquaculture in the country.

The price of fishmeal in Viet Nam depends entirely on protein content. The current average price is VND 150 per percent of protein, such that fishmeal with 60 percent protein costs VND 9 000/kg, though high quality fishmeal from Chile or Peru costs around VND 10 000/kg (prices in May 2005; US$1.00 = VND15 900).

4.2.9 Fish oil

Apart from the small-scale production of oil from pangasiid catfish waste, Viet Nam does not produce fish oil and this commodity is imported from South Korea, Chile and Peru. About 2 000–3 000 tonnes of fish oil is currently used in the feed industry (Edwards, Tuan and Allan (2004). Fish oil is mainly used in formulated feed for tiger shrimp at an inclusion rate of 1–2 percent. In addition, shrimp farmers also use fish oil for top dressing of pelleted feeds because they perceive this to enhance shrimp feeding behaviour. Pangasiid oil is included into farm-made feeds at around 2–5 percent and is also used by some feedmills in *Pangasius* and tilapia feeds.

4.2.10 Soybean meal

Soybean meal is the primary protein component in most commercial animal feed formulations and is also the main protein component in formulated aquafeeds. In 2003 Viet Nam produced 225 300 tonnes of soybeans of which about two-thirds was consumed directly as food products (e.g. tofu, soymilk) with the balance going to animal feeds. The quality of local soybean meal is good (Table 24).

In 2003, Viet Nam's soybean meal imports were estimated at 960 000 tonnes, an increase of 27 percent over the 795 000 tonnes imported in 2002. Argentina and India were the key soybean meal suppliers to Viet Nam. In 2004, soybean meal imports increased by 14 percent over 2003 to 1.1 million tonnes (Huong, 2004).

Soybean meal inclusion rates in shrimp feeds range from 15–20 percent, for omnivorous species between 20–30 percent and for pangasiid catfish can be as high as 40–50 percent, without affecting fish growth (Hung, 2004). Because of the increasing scarcity of trash fish about 38 percent of farmers are now using soybean meal in their

TABLE 24
Nutrient content (percent as fed basis) of soybean meal produced in Viet Nam

Nutrient extract	Dry matter	Crude protein	Crude lipid	Crude fibre	NFE	Ash
Mechanically extracted	86.5	42.6	7.4	5.9	24.7	5.9
Solvent extracted	89.0	44.7	1.5	5.1	32.2	5.5

Source: NIAH (1995)

TABLE 25
Estimation of soybean meal use for aquafeed

Feed types	Production	% soybean meal		Soybean meal used in aquafeed	
		Min	Max	Min	Max
Shrimp feed	180 000	10	15	18 000	27 000
Catfish feed	300 000	20	30	60 000	90 000
Tilapia feed	50 000	20	30	10 000	15 000
Total				**88 000**	**132 000**

TABLE 26
Nutrient content of some common terrestrial and aquatic plants used as feeds or fertilizers in aquaculture

Green fodders	wet weight basis					
	Moisture	Crude protein	Crude lipid	Carbohydrate	Cellulose	Mineral
Duck weed	92.0	1.5	0.2	5.4	0.1	1.1
Water hyacinth	92.9	2.1	6.7	2.6	0.6	0.9
Water morning glory	91.6	1.9	0.8	-	1.4	1.1
Cassava leaf	73.4	5.2	3.5	-	5.0	1.8

Source: Bao Thang Company (2002) (pers. com.)

farm-made formulations. As for most other feedstuffs there are no official statistics of soybean meal use in aquafeed and this was estimated (Table 25) using the same rationale as for the other commodities. The data suggest that some 80 000–130 000 tonnes soybean meal is used in commercial and farm-made aquafeeds.

4.2.11 Other plant proteins
Substantial quantities of groundnut meal and coconut meal are produced in Viet Nam, but for various reasons are not used to any significant degree in farm-made and or commercial aquafeeds. Other oilseed cake meals such as rapeseed meal, palm kernel meal, cottonseed meal are imported for animal feed but not used in aquafeeds.

4.2.12 Green fodder
Green fodders are used as supplemental feeds for herbivorous fish such as grass carp, gourami and silver barb. The common green fodders and their nutrient content are presented in Table 26.

4.2.13 Premix and feed additives
In formulated feeds vitamin and mineral premixes and feed additives play an essential and important role in the enhancement of animal health and physiological function. There are several multinational and local companies in Viet Nam that produce premixes for animal feeds, of which DSM, Nutriway and Bayer are the leading producers. The inclusion rates are usually 0.025 percent for catfish and tilapia feed and 0.1–0.2 percent for shrimp feeds. Other feed additives such as ascorbic acid, lysine, methionine, anti-oxidants, anti mould agents, astaxanthin, feed attractants, feed stimulants, and probiotics are readily available in Viet Nam. All the ingredients for premixes are imported.

5. PROBLEMS AND CONSTRAINTS
The National Development Plan expects the aquaculture sector to produce 2 million tonnes by 2010. With a targeted annual growth rate of over 20 percent, many challenges are likely to arise. There are two ways to achieve the production target. Firstly by increasing the surface area for aquaculture and secondly by intensifying the existing aquaculture practices. Expanding water surface area for aquaculture can be relatively easily implemented in the central highlands, northeastern and northerwestern Viet Nam where population density is low, though these areas often lack adequate water

resources. Converting rice fields and other wetland agriculture ecosystems into fishponds has been an important step in the aquaculture expansion plan since the 1990's in the Mekong Delta and other places. Nevertheless, a continued switch from agricultural to aquaculture will limit rice and other crop production to ensure food security. Therefore, intensification of fish faming is obligatory for the sector to achieve its goals.

However, intensification requires more feeds and nutrient inputs. This may pose problems and constraints in terms of ingredient availability and accessibility and may also have socio-economic implications in respect of feed resource allocation as well as economic consequences for small and medium scale farmers.

5.1 Constraints in feed and feed ingredient availability and accessibility

5.1.1 Herbivorous fish

- *Grass availability, particularly in the dry seasons*: Herbivores, especially grass carp consume grass of up to 60–100 percent body weight per day. A 1000 m^2 fishpond used for culture of grass carp needs 1 to 2 labourers to collect sufficient volumes of grass. In some places, farmers have to travel up to 30 to 50 km to collect enough grass to meet the demand. There are not enough pastures reserved for feed and feeding of fish.
- *Supplemental and alternative feeds for grass carp and other herbivores:* In semi-intensive or intensive systems, grass is not adequate for grow-out and for decreasing the duration of the production cycle. More research is required to deal with the intensification of herbivorous fish culture.

5.1.2 Filter feeding fish

- *Manure availability and accessibility*: Integrated farming (e.g. VAC systems) is the most appropriate technology for small-scale farmers and is actively promoted. However, manure is not available and/or accessible in many places and farmers need to be educated on the value of applying manure to fish ponds.
- *Alternative nutrient inputs*: Inorganic (urea and DAP) fertilizers are readily available and accessible in Viet Nam. However, farmers are poorly educated in the use of inorganic fertilizers. There is a need for improved training and extension services.

5.1.3 Omnivorous fish

- *Trash fish shortage*: As indicated above the pangasiid catfish industry annually needs 60 000–180 000 tonnes trash fish and this will be doubled if catfish production reaches the target of 0.5 million tonnes in 2010. The supply of trash fish is the main limiting factor to achieving the above production target.
- *Fishmeal shortage*: Viet Nam is not capable of producing adequate volumes of fishmeal for the animal and aquaculture feed industries. The country therefore has to import most of its fishmeal requirements. Future world supply of fishmeal may constrain the development of the aquaculture sector in Viet Nam.
- *Alternative ingredients to fishmeal/trash fish*: Oilseed cake meals are good protein sources to partially replace fishmeal or trash fish in catfish and tilapia feeds. Feedmillers need to examine the use of alternatives such as sunflower oilseed cake and others. Soybean meal is readily available on international markets. Other local oilseed cake meals are available but the quality of these commodities has to be improved such that they can be used more effectively in aquafeeds. Small- and medium-scale farmers are constrained to a much greater extent in the search for alternatives than the feedmills.

5.1.4 Carnivorous fish

- *Trash fish shortage*: Trash fish is considered to be the most limiting factor in carnivorous fish culture. The development of marine fish and snakehead culture has placed enormous strain on supplies.
- *Trash fish seasonality*: Trash fish supply is becoming more unstable over time. Its high seasonal availability is a severe constraint for carnivore aquaculture.

5.1.5 Shrimp

- Shrimp culture in semi-intensive and intensive systems require large volumes of feeds and nutrients and will be severely constrained if availability and accessibility of feed ingredients become problematic. The two major constraints facing the sector are future fishmeal shortages and the high tax on premixes and imported animal feed ingredients.

5.2 Social and economic constraints

- *Traditional feeding practices*: The study by Hung, Truc and Huy (2007) clearly shows that farmers need to change their traditional feeding practices, which depend largely on trash fish, if they are to remain profitable.
- *Access to credit:* A recent study by Thi (2005) showed that 83 percent of fish farmers in An Giang province face credit constraints. It may not be wrong to assume that most small- and medium-scale farmers in other areas face similar problems in finding adequate credit to buy feed ingredients and nutrients. Those that have access to banks may obtain a loan at a monthly interest rate of one percent. Those that do no have access to the formal banking sector have to take "hot loans" with monthly interest rates of 5–6 percent.

5.3 Farm-made feeds

Farm-made feeds are traditionally used on small and medium-scale farms. The intensification of aquaculture and reduced availability of trash fish and fishmeal will place severe constraints on the preparation of farm-made feeds by these farmers.

- Farm-made feeds for pangasiid catfish, marine carnivorous fish, lobsters, freshwater prawns, snakeheads are traditionally composed of trash fish and rice bran and other ingredients. The availability of trash fish is highly seasonal, hence the preparation of farm-made feeds using alternatives such as fishmeal and soybean meal are promoted but the practice is constrained by farmer habits. Commercial feed mills know how to compensate for nutrient deficiencies such as lysine and methionine but farmers do not. Farmers need to be trained in the use of alternatives such as soybean meal and this could be achieved through closer liaison between farmer associations and ingredient distributing companies.
- Although aquafeed ingredients are locally available, small-scale aquaculture farmers do not have adequate and ready access to good quality ingredients.
- Due to lack of knowledge farmers do not pay enough attention to storing their feed ingredients in an appropriate manner to prevent oxidation. Hence they have little understanding of feed quality and its effect on production and fish health.
- The high seasonal abundance of golden snails is a constraint for small- and medium-scale freshwater prawn farmers.
- Preparation of farm-made feeds for tiger shrimp is not a simple task. Several attempts have been made to train farmers in pellet production using local ingredients such as rice bran, wheat flour and trash fish. However, all attempts have failed because of high pond pollution levels caused by poor feed quality. It is not surprising that farmers have not adopted the procedures.

5.4 Commercially formulated feeds

The rapid advances and growth in the aquafeed industry for catfish and shrimp feeds poses several constraints.

- Commercially formulated feeds are expensive and feed cost amounts to 70–80 percent of total production costs in intensive systems. Shrimp farmers can accept the high feed prices since the benefits of higher survival compensates for the higher price. However, catfish cage farmers are severely constrained by the price of commercial feeds and are essentially forced to continue using trash fish based feeds. In the less traditional catfish farming areas in the Mekong Delta farmers are now growing catfish in ponds, in which FCRs using formulated feeds is better than in cages (see Hung, Truc and Huy, 2007). Similarly, only red tilapia cage farmers who are in close proximity to urban markets can justify the use of formulated pellets. Moreover, there is a traditional perception that farm-made feeds, using trash fish as the principal component, are superior to commercial feeds (see Hung, Truc and Huy, 2007).

6. RECOMMENDATIONS

- For the feeding for herbivorous fish the use of locally available agriculture by-products is highly recommended to maximise the use of local sources of protein in resource-poor and in remote areas. Development agencies must appreciate this and develop appropriate trials and demonstrations to establish these techniques.
- The use of VAC systems must be promoted for the farming of omnivores and filter feeders to maximise the use of on-farm resources.
- To maximize land use and increase fish yield greater use should be made of commercial feeds and the use of alternative ingredients for farm-made feeds. The replacement of trash fish by plant proteins, such as soybean meal, should be the first priority and farmers need to be trained in formulating plant protein based feeds.
- The feed industry in association with government agencies and universities must pay greater attention to the nutritional requirements of pangasiid catfish, such that diet formulation is optimised and least cost feeds can be produced.
- The high feed cost in Viet Nam makes the country's shrimp and catfish producers uncompetitive. The main reason for the high feed prices is the high import duty and tax on feed additives and imported animal feed ingredients. This must to be addressed by the appropriate authorities.
- The massive use of fresh trash fish is a major constraint to snakehead farming. Research on the use of pelleted feeds for carnivores such as snakehead and grouper has to be given priority. In this regard, better use must be made of fish processing by-products. Further studies are also needed to promote the wise use of agricultural by-products for fish farming. In particular the research should focus on trash fish replacement.
- Government should develop enabling policies and conditions that will lead to a reduction in feed prices. This will lead to greater international competitiveness for the export of fish fillets and shrimp.
- A database on the nutritional requirements of *Pangasius* catfish must be developed that may serve as a reference for the formulation of commercial and farm-made feeds. Investigations on the use of low value cultured fish to feed carnivorous fish should also be carried out.
- The knowledge base of extension workers on aquaculture nutrition and feeding must be enhanced such that farmers can intensify their activities.
- The Ministry of Fisheries must develop improved fisheries management regulations that prevent over exploitation of trash fish.

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APPENDIX
QUALITY NORMS, FEED STANDARDS, FEED SPECIFICATIONS AND FEEDING GUIDELINES OF AQUAFEEDS IN VIET NAM

A.1. Quality standard (28TCN 102: 2004) for formulated shrimp (*Penaeus monodon*) feeds

Feed type	Shape of feed	Size of shrimp (g)
1	Crumbles	0.01–0.2
2	Crumbles	0.2–1.0
3	Crumbles or pellet	1.0–5.0
4	Pellet	5.0–10.0
5	Pellet	10.0–20.0
6	Pellet	>20.0

A.2. Physical, chemical, micro-organism and veterinary hygiene safety standard for formulated shrimp (*Penaeus monodon*) feeds

Standard		Feed type					
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
1	Diameter of pellet (mm) not bigger	0.6	0.8	1.2	1.8	2.2	2.5
	Length/diameter ratio	1.5–2.5					
2	Broken rate (% weight) not higher	2					
3	Durability not lower (hours)	1					
4	Crude energy (kcal/kg feed) not lower	3 400	3 400	3 200	3 200	3 000	3 000
5	Moisture (% weight) not higher	11					
6	Crude protein (% weight) not higher	42	40	39	38	37	35
7	Crude lipid (% weight)	6–8	6–8	5–7	5–7	4–6	4–6
8	Crude fibre (% weight) not higher	3	3	4	4	5	5
9	Ash (% weight) not higher	14	14	15	15	16	16
10	Sand (ash un-dissolvable in HCl 10%) (% weight) not higher	1	1	2	2	2	2
11	Calcium (% weight) not higher	2.3					
12	Calcium/phosphorus ratio	1.0–1.5					
13	NaCl (% weight) not higher	2.5					
14	Lysine (% weight) not lower	2.1	2.1	1.8	1.8	1.7	1.7
15	Methionine (% weight) not lower	0.9	0.9	0.8	0.8	0.7	0.7
16	Alive insects	Not permitted					
17	Pathogenic bacterium (*Salmonella*)	Not permitted					
18	*Aspergillus*	Not permitted					
19	*Aflatoxin*	<10 ppb					
20	Antibiotic and chemical is not allowed to be used by Resolution No. 01/2002/QD-BTS, January 22, 2002 of Ministry of Fisheries, Viet Nam	Not permitted					

A.3. Quality standard (28TCN 188: 2004) of formulated feed for pangasius catfish (*Pangasius* sp.)

Feed type	Shape of feed	Size of shrimp (g)
1	Crumble or pellet	<1
2	Crumble or pellet	1–5
3	Pellet	5–20
4	Pellet	20–200
5	Pellet	200–500
6	Pellet	>500

A.4. Physical, chemical, micro-organism and veterinary hygiene safety standard for formulated catfish feed

Standard		Feed type					
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
1	Diameter of pellet (mm) not bigger	1	1.5	2.5	5	10	12
	Length/diameter ratio			1–1.5			
2	Broken rate (% weight) not higher			2			
3	Durability not lower (hours)			30			
4	Crude energy (kcal/kg feed) not lower	3 300	2 800	2 400	2 100	1 800	1 500
5	Moisture (% weight) not higher			11			
6	Crude protein (% weight) not higher	40	35	30	26	22	18
7	Crude lipid (% weight)	8	6	5	5	4	3
8	Crude fibre (% weight) not higher	6	6	7	7	8	8
9	Ash (% weight) not higher	16	14	12	10	10	10
10	Sand (ash un-dissolvable in HCl 10%) (% weight) not higher			2			
11	Phosphorus (% weight) is not higher			1			
12	NaCl (% weight) not higher			2.5			
13	Lysine (% weight) not lower	2.0	1.8	1.5	1.3	1.1	0.9
14	Methionine (% weight) not lower	0.9	0.8	0.7	0.6	0.5	0.4
15	Alive insects			Not permitted			
16	Pathogenic bacterium (*Salmonella*)			Not permitted			
17	*Aspergillus*			Not permitted			
18	*Aflatoxin*			<10 ppb			
19	Antibiotic and chemical is not allowed to be used by Resolution No. 01/2002/QD-BTS, January 22, 2002 of Ministry of Fisheries, Viet Nam			Not permitted			

A.5. quality standard (28 TCN 189: 2004) of formulated feed for tilapia (*Oreochromis* sp.)

Feed type	Shape of feed	Size of fish (g)
1	Crumble or pellet	5
2	Pellet	5–10
3	Pellet	10–20
4	Pellet	20–200
5	Pellet	200–500
6	Pellet	>500

A.6. Physical, chemical, micro-organism and veterinary hygiene safety standard of formulated feed for tilapia (*Oreochromis* sp.)

	Standard	Feed type					
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
1	Diameter of pellet (mm) not bigger	1.0	1.5	2.0	4.0	4.0	6.0
	Length/diameter ratio	1.0–1.5					
2	Broken rate (% weight) not higher	2					
3	Durability not lower (hours)	30					
4	Crude energy (kcal/kg feed) not lower	3 200	3 000	2 860	2 800	2 750	2 700
5	Moisture (% weight) not higher	11					
6	Crude protein (% weight) not higher	40	35	30	27	25	20
7	Crude lipid (% weight)	6	6	5	5	4	4
8	Crude fibre (% weight) not higher	5	5	6	6	7	7
9	Ash (% weight) not higher	19					
10	Sand (ash un-dissolvable in HCl 10%) (% weight) not higher	1	1	2	2	2	2
11	Calcium (% weight) not higher	2.5					
12	Calcium/phosphorus ratio	1.0–1.5					
13	NaCl (% weight) not higher	2.5					
14	Lysine (% weight) not lower	1.7	1.6	1.4	1.3	1.1	0.9
15	Methionine (% weight) not lower	1.0	0.9	0.8	0.7	0.6	0.5
16	Alive insects	Not permitted					
17	Pathogenic bacterium (*Salmonella*)	Not permitted					
18	*Aspergillus*	Not permitted					
19	*Aflatoxin*	<10 ppb					
20	Antibiotic and chemical is not allowed to be used by Resolution No. 01/2002/QD-BTS, January 22, 2002 of Ministry of Fisheries, Viet Nam	Not permitted					

A.7. Feed specifications and feeding guidelines for catfish and tilapia

Brand name/number	Feed size (mm)	Crude protein min. (%)	Fish weight (g)	Feeding rate (% body weight)	Feeding frequency (time/day)
Tilapia and catfish fingerling					
Aquaxcel-7404	<1.0	42	<1.0	15	>10
Aquaxcel-7414	1.0	40	1–2	10	>5
Aquaxcel-7424	1.2	40	2–5	10	>5
Aquaxcel-7434	1.5	35	5–20	5–10	>5
Aquaxcel-7444	1.5	35	>20	5–10	>5
Catfish grow-out					
7644	1.8	28	20–300	>5	5
7654	3.0	26	30–300	3–5	4
7664	3.0	22	300–500	2–3	3–4
7674	4.5	25	200–500	2–3	3–4
7684	4.5–6.0	22	>500	2–3	3–4
7694 NC	6.0	22	>500	2–3	3–4
7694 ND	10.0	22	>500	1–2	3
Tilapia grow-out					
	3	28	200–500	2–3	4
	4.5	25	>500	2–3	3–4
	4.5	25	>500	2–3	3–4

Source: Cargill Company (pers. com.)

A.8. Feed specifications, proximate composition and feeding guidelines for shrimp

Brand name	Feed type (mm)	Crude protein (minimum %)	Crude lipid (minimum %)	Mineral (maximum %)	Crude fibre (maximum %)	Calcium (minimum %)	Phosphorus (minimum %)	Shrimp size (g)	Age (days)	Feeding rate (% body weight)	Feeding frequency (time/day)	Quantity of feed for 100 000 shrimp (kg/day)
TB1	Powder	42	6	16	3	3.5	1.5	<0.2	1–10	12–10	2–4	0.24–1.6
TB2	Crumble	42	6	16	3	3.5	1.5	1–3	18–28	8–7	2–4	8–18
TB3	Crumble	42	6	16	3	3.5	1.5	1–3	18–28	8–7	2–4	8–18
TBS1	Pellet 1.8x2-4	42	6	16	3	3.5	1.5	3–6	25–50	7–5	3–4	18–28
TBS2	Pellet 2.0x3-5	40	6	16	3	3.5	1.5	6–10	40–63	5–4	3–4	28–33
TBG1	Pellet 2.2x3-4	38	6	16	3	3.5	1.5	10–15	60–82	4–3	4–5	33–49
TBG2	Pellet 2.2x4-5	38	6	16	3	3.5	1.5	15–21	77–106	4–3	4–5	49–60
TBF	Pellet 2.2x5-7	36	6	16	3	3.5	1.5	> 20g	100–120	3–2	5–6	60–76

Source: Tomboy Company (pers. com.)

Case study on the use of farm-made feeds and commercially formulated pellets for pangasiid catfish culture in the Mekong Delta, Viet Nam

Le Thanh Hung, Luu Thi Thanh Truc and Huynh Pham Viet Huy
Faculty of Fisheries
Nong Lam University, Ho Chi Minh City
Viet Nam

Hung, L.T., Truc, L.T.T. and Huy, H.P.V. 2007. Development of the aquafeed industry in India. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 363–377.

SUMMARY

This survey was carried out during the period September to December 2005 and is based on data obtained from 107 fish farmers from three different locations in the Mekong Delta in Viet Nam. Feeding practices and culture facilities for pangasiid catfish varied widely, depending on location, culture tradition and feed types. In Viet Nam, cage culture of pangasiid catfish started in Chau Doc and then moved downstream to other locations along the river such as Long Xuyen and Can Tho/Vinh Long. It is expected that pond culture of pangasiids will soon be the predominant culture method for these species.

Traditional farm-made feeds consist mainly of trash fish and rice bran. However, recent changes in the availability of trash fish have resulted in significant increases in the price of farm-made feeds, which is affecting aquaculture throughout the country. The study revealed that about 39 percent of farmers now use soybean meal for the manufacture of farm-made feeds at inclusion levels ranging between 10 and 30 percent. The incorporation of other ingredients, such as fishmeal, is still a relatively rare occurrence and only 2 to 20 percent of farmers use such alternatives, depending on locality.

The production of pelleted feeds for catfish started in 1998. Since then it has expanded into all catfish growing areas in the Delta. Pelleted feeds appear to have several advantages, e.g. improved growth and food conversion. Despite the advantages farmers in the more traditional catfish growing areas still prefer farm-made feeds. It was also noted that even those farmers who regularly use pellets, revert to farm-made feeds during the final months of grow-out or when the price of fish decreases. The cost of production using pellets is higher than for farm-made feeds.

Although the use of commercial pelleted feed is expanding quickly, farm-made feeds still play an important role in pangasiid aquaculture in Viet Nam. A cost/benefit analysis revealed that the production cost in ponds, using farm-made feeds, is generally lower than in cages. Hence farmers adjust their feeding practices depending on the price of the fish at harvest.

To reduce the cost of farm-made feeds, farmers need to diversify and incorporate alternative ingredients into their feed formulations. To ensure the sustainability and future growth of pangasiid catfish aquaculture in the Mekong Delta there is a need for researchers and extension workers to focus on developing alternative and cost effective feed formulations and appropriate feeding strategies.

1. INTRODUCTION

In 2004, catfish production in Viet Nam amounted to some 260 000–300 000 tonnes, which comprised about 56 percent of freshwater aquaculture production in the Mekong River Delta, and constituted about 10 percent of national aquaculture export earnings (Phuong *et al*., 2005). It is widely recognized as one of the most important aquaculture sectors in Viet Nam. The Mekong Delta is the most important region for pangasiid aquaculture in Viet Nam. The most commonly farmed species are *Pangasius hypophthalmus*, *P. bocourti* and *P. conchophilus*. Cages, ponds and net pens are the most common farming practices in the region. Table 1 summarizes the trends in pangasiid aquaculture in the Mekong Delta.

Culture practices as well as the use of different types of feed vary widely, depending on location, available facilities and infrastructure. Farm-made feeds, in which trash fish forms the major protein component, are the most widely used in the Delta region. However, the use of trash fish in farm-made feeds currently poses several constraints on pangasiid aquaculture practices and development in the Delta. The most serious of these is the quality and availability of fish, which often arrives on site in a highly decomposed form. This is principally because fish is kept for 7–10 days at sea in unsuitable conditions and is not chilled during transportation to farming areas. This has led to the promotion of the use of formulated pellets under certain conditions. Pelleted feeds have several advantages over farm-made feeds. These include availability, lower feed conversion ratios and reduced environmental impact.

Previously, trash fish from the wetland areas of the Delta, especially during the flood season, was readily available and marine trash fish was only used as an alternative during the dry season. Over-fishing of the wetlands and the dependence on marine trash fish, even during the flood season, has increased the price of the commodity to a point at which the potential economic benefits may be negligible. It is mainly for this reason that farmers now seek alternative ingredients, such as soybean meal and other plant protein sources that are available in the Delta. Collectively, these issues have constrained the development of the catfish farming sector in the region.

Recent research has shown that pangasiid catfish can be reared on soybean meal based diets without any negative effects (Hung, 2003). Nevertheless, the use of trash fish is still a common practice in the catfish culture industry in the Delta. The present study was designed to obtain a better understanding of current feed use patterns and to assess the relative economic merits of farm-made and formulated feeds and to advise farmers accordingly. The objectives of the study were:

- to evaluate the use of farm-made feed versus formulated pellets in different locations where catfish culture is a common practice;
- to conduct a cost/benefit analysis of the two feed types to compare the production costs; and
- to identify the potential and future development of farm-made feeds for pangasiid catfish production in Viet Nam.

TABLE 1
Catfish culture area and production trends in the Mekong River Delta during 1997-2004

Category	1997	1999	2001	2003	2004 (estimated)	Growth rate (%/year)
Culture area (ha)	**1 290**	**2 253**	**2 305 5**	**2 717**	**3 200**	**24.6**
Ponds (area)	1 290	2 253	2 288	2 652	2 991	21.9
Cages (units)	1 300	1 621	2 539	2 271	1 872*	7.3
Production (tonnes)	**40 250**	**86 775**	**114 289**	**162 778**	**255 044**	**88.9**
Pond	22 550	50 330	66 660	109 105	178 624	115.3
Cage	700	19 005	37 418	48 068	45 748	-

*The lower number of cages in 2004 is a direct consequence of the higher unit production cost (see later).

Source: MOFI (2004)

2. METHODS

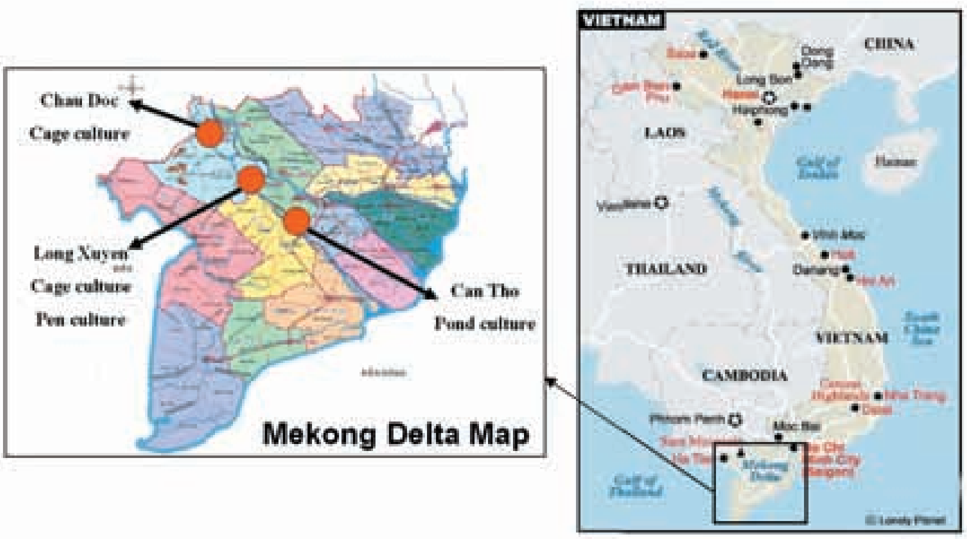
A structured questionnaire was developed and applied on 107 randomly selected farmers, such that the various catfish farming practices in the Mekong Delta were represented (Table 2). The survey was conducted in three locations during the period July to November 2005. The three survey areas were Chau Doc, Long Xuyen, and Can Tho/Vinh Long. Approximately 80–90 percent of catfish production in the Delta originates from these areas. Each location has its own farming traditions.

Historically, Chau Doc is the cradle of catfish cage culture in the Mekong Delta. Presently, cage culture is still the dominant form of pangasiid culture. For this reason 30 representative cage culture operators were selected from this region. The city of Long Xuyen, in An Giang province, is 30 km downstream from the town of Chau Doc. Just prior to the survey period the price of catfish dropped and many of the cage farmers in the region had switched to pond culture of other species. A total of 15 cage farmers were interviewed in this area. Pen culture is also practiced in this area and because of the similarities between pen and pond culture, the results for 14 pond and pen farmers were pooled.

Because of similar farming practices, traditions and physical conditions Can Tho and Vinh Long were grouped as the third study location. The locations are about 30–35 km downstream from Long Xuyen city. These two localities are the main representative areas for pond farming practices. Of the 48 interviewees in the area, 46 were pond farmers and two were cage farmers.

Based on the type of farming and feed use practices in each of the three areas a random selection of farmers was made so that the current status of the two feeding practices in different culture facilities in respective study areas was well represented in the data.

FIGURE 1
Map of the Mekong Delta, showing the three study locations in Viet Nam



Of 107 farmers selected for the survey, 48 households were further interviewed using an economic evaluation questionnaire to carry out cost/benefit analyses. The sample size for this exercise was smaller than the overall sample because only a small proportion of surveyed farmers were

TABLE 2
Sample allocation in the three main catfish culture areas

Location	Culture facilities		Total
	Cage	Pond	
Chau Doc	30		30
Long Xuyen	15	14	29
Can Tho and Vinh Long	2	46	48
Total	**47**	**60**	**107**

able to provide detailed economic information (Table 3).

All data were coded and entered into Microsoft Excel spreadsheet for analysis.

TABLE 3
Sample size of farmers participating in the cost/benefit analysis

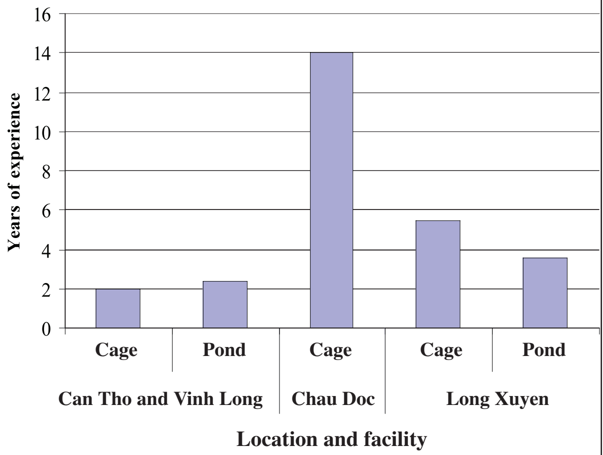
Location	Culture facility		Total
	Cage	Pond	
Can Tho and Vinh Long	0	27	27
Chau Doc	5	0	5
Long Xuyen	9	7	9
Total	**14**	**34**	**48**

3. RESULTS AND DISCUSSION

3.1 Experience of catfish farmers

Figure 2 shows the average years of experience of farmers in the three areas. In Chau Doc, where cage culture of catfish originated, farmers on average have over 14 years of experience, which is significantly more than in the other two areas, viz. 5.5 for Long Xuyen and two in Can Tho and Vinh Long. This has had a significant influence on culture practices. For example, Chau Doc farmers seem to be more conservative concerning the application of new techniques. In fact, many of the farmers started catfish culture before 1979 simply by following their parents' occupation (Action Aid, 2002).

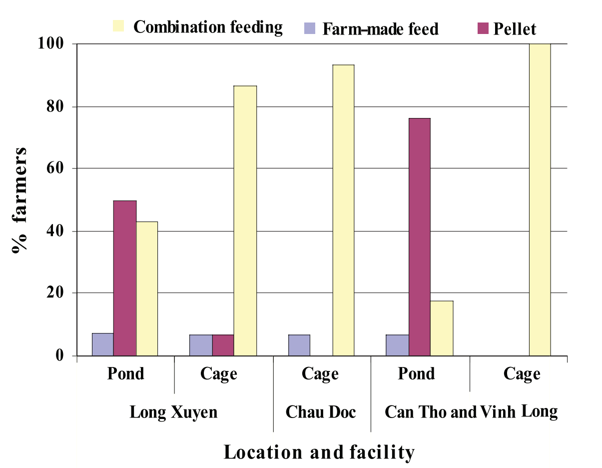
FIGURE 2
Average years of experience of farmers in the three sampling locations



The second most experienced farmers are in Long Xuyen where catfish farming developed soon after the evolution of catfish cage culture in Chau Doc. This location is also the second most important area for catfish culture along the Mekong River. On average, farmers in Long Xuyen have approproximately 5.5 years of experience in cage culture and approproximately 3.6 years experience in pond culture. Although many of the farming traditions have been passed on from Chau Doc, catfish culture in Long Xuyen has its own characteristics due to the difference in topography. In this region farmers make use of the tidal range for water exchange in ponds and as a result can practice both cage and pond culture.

Farmers in the Can Tho and Vinh Long area are the most recent practitioners of catfish farming in the Delta, and pond culture in this area is the dominant farming system. In this region, farmers have an average experience of about 2.4 years. Cage culture is not commonly practiced in Can Tho and Vinh Long due to the nature of the river system. The water borne river traffic in Can Tho and Vinh Long is intensive and this is a major constraint to cage culture.

FIGURE 3
Feed use patterns under different culture conditions in the three locations



3.2 Feeds and feeding practices

Feed use

The survey data suggests that type of feed depends on the farming system. A high percent of pond farmers in Can Tho and Vinh Long use commercially formulated pellets for the entire production cycle (Figure 3). The findings of the present study clearly show the evolution that has taken place since the study undertaken by Phu and Hien (2003). Approproximately 76 percent of interviewed pond farmers in Can Tho and Vinh Long now use pellets for the entire grow-out cycle. This is in contrast to the 46 percent of farmers in Can Tho province and the 5 to 10 percent of farmers in other provinces that used pellets, as reported by Phu and Hien (2003). Around 17 percent of pond farmers use farm-made feed in combination with pellets, whilst only 6.5 percent of the farmers use exclusively farm-made feeds. In total only about 24 percent of farmers in this region now use farm-made feeds. Combination feeding is however used by 100 percent of cage farmers.

In the Long Xuyen area, approximately 50 percent of pond farmers use farm-made feeds, although most use these feeds in combination with pellets. The most widely used practice by cage farmers (87 percent) is to use pellets during the initial stages of rearing and farm-made feeds for the finishing stage (see later). Only a small proportion (7 percent) of farmers who practice cage culture use farm-made feeds exclusively for the duration of the production cycle. In general, combination feeding is the most prevalent feeding practice in the region.

In contrast to the feeding practices in Long Xuyen and Can Tho/Vinh Long, more than 93 percent of cage farmers in Chau Doc still use farm-made feeds as the principal feed and only use it in combination with pellets during the first month after stocking. The remainder use only farm-made feeds for the entire culture cycle. Therefore, nearly 100 percent of cage farmers in this area use farm-made feeds for the greater part of or the entire production cycle. This is very similar to the results reported by Phu and Hien (2003) and illustrates the tradition bound nature of the farmers in this area. The use of farm-made feeds here is principally related to the low price of the feed in comparison to pellets in the past, which is of course a decisive factor for any aquaculture business. Only a few farmers noted that the availability of ingredients influenced their decision to choose farm-made feeds over formulated pellets.

From the above it is evident that farm-made feeds are more generally used in Long Xuyen and Chau Doc, while commercially formulated feeds are more commonly used in pond culture systems in Long Xuyen and Can Tho/Vinh Long. It was interesting to note that even those farmers who use mainly farm-made feed, usually also use pellets during the first month of culture when the fish require high quality feed. Hence, it is difficult, if not impossible, to determine the proportion of fish produced using farm-made feeds and formulated feeds. However, based on the 300 000–350 000 tonnes of formulated feed produced in 2004 and a feed conversion ratio of 1.5–1.8 it is estimated that formulated feeds account for approximately 200 000 tonnes of fish. Total production of catfish in 2004 was 300 000 tonnes, suggesting that the remainder of the catfish (100 000 tonnes) were produced using farm-made feeds. The best estimate for the proportional contribution to total production attributed to farm-made feeds and pellets is around 1:1.9.

Feeding practices

The production cycle for pangasiid catfish is divided into three phases, viz., (1) the first month after stocking of the fingerlings, (2) the main growth period of around 4 to 5 months and (3) the final month before the fish are harvested. Feeding practices are closely related to these phases and as mentioned above also vary according to the location. The variation in feeding practices by farmers who mainly use farm-made feeds is illustrated in Figures 4, 5 and 6.

In Long Xuyen, pellets are commonly used in the first month in both cages and ponds. Some 93 and 86 percent of cage and pond farmers used pellets during the first month, respectively (Figure 4). The reasons for using pellets in the first month were diverse. However, the main reason was that farmers were of the opinion that small fish are better adapted to feed on pellets and that pellets also provide better nutrition.

Farmers were also of the opinion that the use of pellets reduced mortalities during the early rearing phase. During the middle months farmers use farm-made feeds, while during the final month some farmers keep on using farm-made feed. Others use a combination of farm-made feeds and pellets. Appropproximately 28 percent of cage culture farmers in Long Xuyen combine pellets with farm-made feeds during the final month, while only 14 percent of pond farmers follow this practice. Farmers were of the opinion that feeding pellets in the final month improved the quality of the fish and resulted in a whiter meat at harvest. Farmers were also of the opinion that feeding fish with pellets accelerates the growth rate, such that the fish can be harvested earlier. The findings suggest that farmers recognize the benefits of pelleted feeds and would also use them for the entire cycle provided that the feed is affordable.

Feeding practices by cage farmers in Chau Doc is similar to those in Long Xuyen. About 83 percent of farmers use pellets during the first month and 90 percent use farm-made feeds during the middle months (Figure 5). However, in contrast to farmers in Long Xuyen, approximately 10 percent of farmers in Chau Doc use a combination of the feeds from the beginning to the end of the production cycle. Moreover, a higher percent of farmers (37 percent) in Chau Doc apply combination feeding in the final month than in Long Xuyen.

As previously mentioned, Can Tho and Vinh Long are relatively new catfish farming areas. The only real difference in these areas, in comparison with Chau Doc and Long Xuyen, is that a higher proportion of farmers (73 percent) use pellets during the first month.

FIGURE 4
Feed use practices in cages and in ponds during the three rearing phases in Long Xuyen

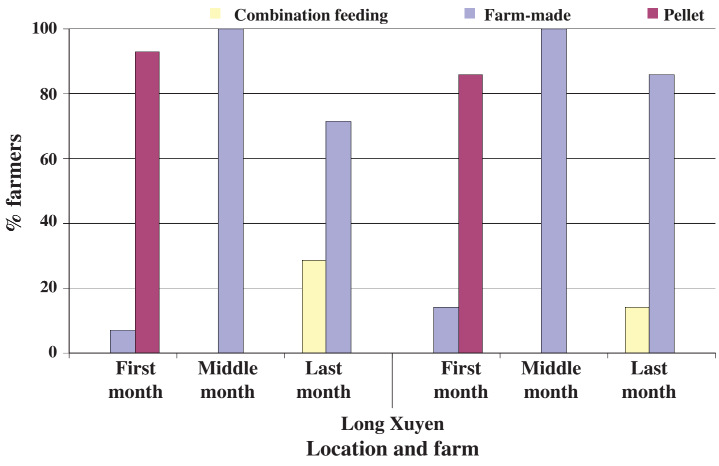


FIGURE 5
Feed use practices in cages during the three rearing phases in Chau Doc

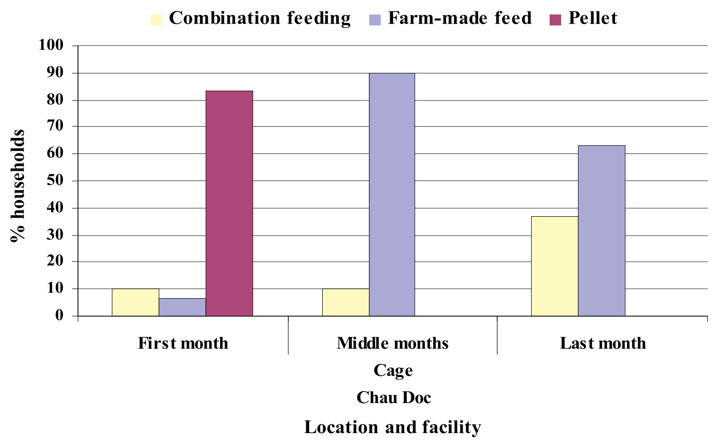


FIGURE 6
Feed use in ponds during the three rearing phases in Can Tho and Vinh Long

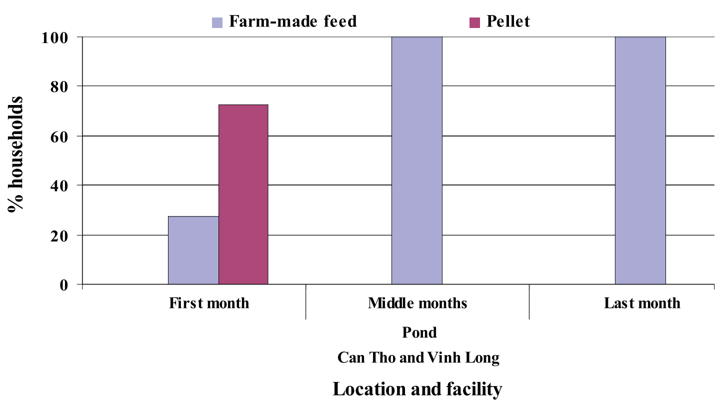


FIGURE 7
Farmer perception on the efficacy of farm-made feeds and pellets

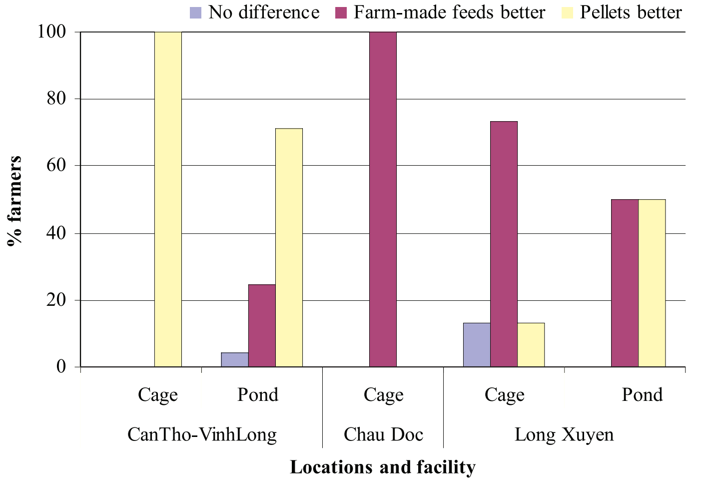
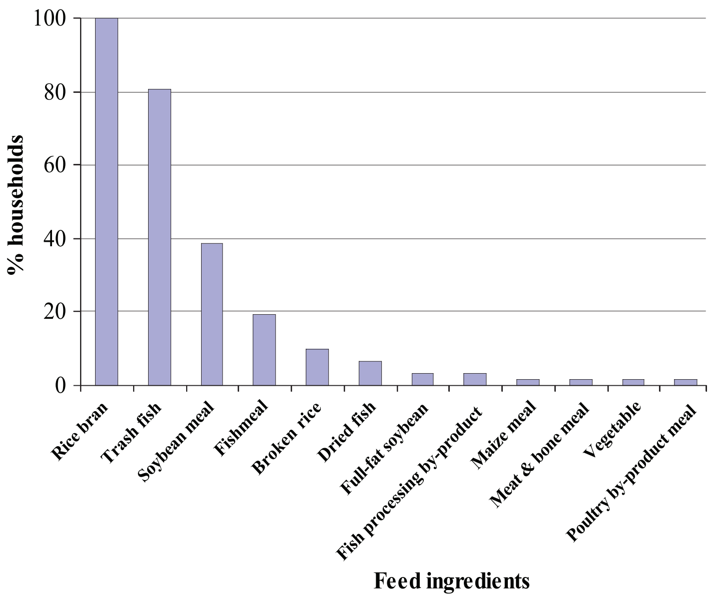


FIGURE 8
Feed ingredients used by fish farmer households for preparation of farm-made feeds



3.3 Farmer perceptions on the efficacy of different feed types

Commercial pellets are only used by farmers if there are known or perceived advantages over other feed types. Because of the high proportional use of pellets in Can Tho and Vinh Long it is clear that most farmers in these areas consider pellets to be more effective than farm-made feeds. On the contrary, 100 percent of cage farmers in Chau Doc and nearly 80 percent in Long Xuyen use farm-made feeds either exclusively or in combination with pellets. This suggests that they perceive farm-made feeds to be superior to pellets. However, this perception may be clouded as farmers in these areas are more conservative and averse to changes.

3.4 Preparation of farm-made feeds

Traditionally farm-made feeds were composed of rice bran and trash fish at a ratio of 1:1 or 2:1, depending on the production phase. Besides rice bran and trash fish farmers now also use other ingredients such as soybean meal, fishmeal, corn meal, dried fish, meat-bone meal and poultry by-product meal. Figure 8 shows the proportion of fish farmer households using different ingredients for the manufacture of farm-made feeds. The data show that all farmers who make their own feeds use rice bran as an energy source, whilst a very small proportion use broken rice or corn meal instead of rice bran. Several protein sources are used, though the majority of farmers (80 percent throughout the Delta) use trash fish. Soybean meal is the second most important protein source used by farmers (39 percent of farmers). It is either used as an alternative or as a supplement to trash fish. Farmers in the Mekong Delta have recognized the financial benefits of such substitutions in order to reduce production cost during the period when the supply of trash fish is low. Moreover, farmers also use soybean meal as an alterative protein source because of the reduced availability of trash fish and the increasing price of this commodity. Farmers appear to have a lower preference for other alternatives such as fishmeal, by-products of fish processing, meat-bone meal and poultry by-product meal. Furthermore, it was of interest to note that farmers in Chau Doc only used trash fish and rice bran for feed preparation, whilst

TABLE 4
Percent of farmers using different feed ingredients at various inclusion rates for farm-made feeds

	Inclusion rates of different ingredients (% as fed basis)			
Ingredient	**>50**	**31–50**	**10–30**	**<10**
Rice bran	66.1	32.2	1.7	0.0
Broken rice	0.0	33.3	66.4	0.0
Corn meal	-	-	100	-
Trash fish	4.0	36.0	58.0	2.0
Fishmeal	0.0	0.0	66.6	33.4
Dried fish	0.0	25.0	75.0	-
Soybean meal	0.0	4.2	79.2	16.6
Full fat soybean	0.0	0.0	100.0	0.0
Fish processing by-product	0.0	0.0	50.0	50.0
Meat and bone meal	-	-	-	100
Poultry by-product meal	-	-	-	100

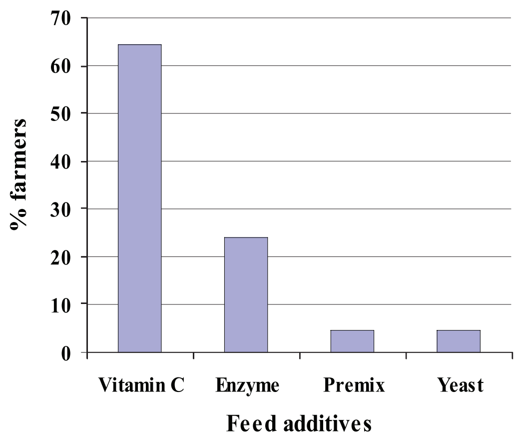
those from the other regions were more open to change and used alternative ingredients to reduce their dependency on trash fish.

The inclusion rates of ingredients in farm-made feeds varied between farmers, depending on perceptions, tradition of feed preparation and the availability of ingredients. In general, rice bran forms the bulk of their formulation and is included at over 50 percent by 66 percent of all farmers (Table 4). Broken rice is also commonly used but at inclusion levels of 10–30 percent (66 percent of farmers). The reason for the use of rice bran is its low price and high availability. Trash fish is the most important protein source. Inclusion rates vary from 10–30 percent (58 percent of farmers) and from 30 to 50 percent (36 percent of farmers). These differences can be attributed to traditional feed preparation practices. The second most commonly used protein ingredient is soybean meal and is used at inclusion rates of 10–30 percent (79 percent of farmers). The only other ingredient of consequence is the by-product of fish processing, which is included by some farmers at between 10 to 30 percent. The data suggest that pangasiid farmers in the Mekong Delta are actively beginning to seek alternative ingredients for their farm-made feed preparations.

In addition to the main ingredients, farmers often mix readily available feed additives into their preparations. Among others, these may include vitamin C, lysine, methionine, anti-oxidants, probiotics, brewer's yeast, enzymes, vitamin and mineral premixes. Figure 9 shows that about 65 percent of the interviewees use vitamin C to improve fish health and up to 24 percent of farmers use enzymes to increase feed digestibility.

Normally, ingredients are mixed, cooked and extruded into sticky long strings (see Figure 13) and are fed to the fish in a wet form. In some places in Can Tho and Vinh Long farmers only cook the broken rice to form a binding paste and then mix it with the other ingredients before extrusion. This method is called the partial cooking process in which premixes and feed additives are added at higher rates in comparison to the complete cooking process. The fuels to cook the ingredients include rice and cashew husks and rubber tyres, though most farmers use rice husks because it is cheap and available throughout the year.

FIGURE 9
Percent of farmers using feed additives in preparation of farm-made feeds

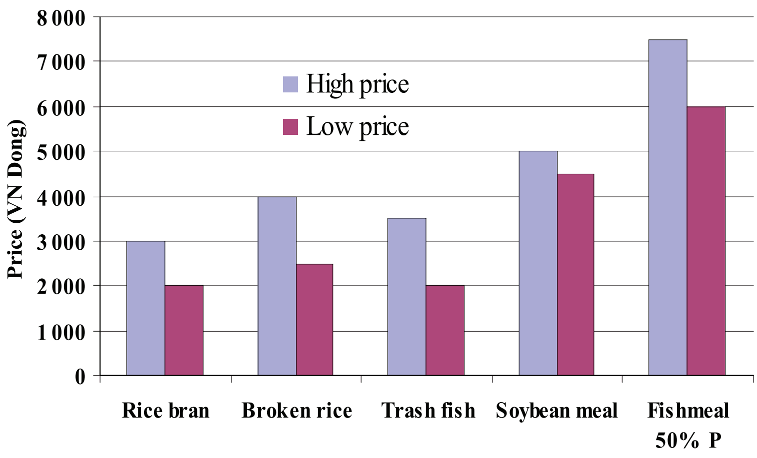


The survey identified nine major feed formulations (Table 5). These diets have relatively low protein levels for a carnivorous species and range from 13.6 to 31.5 percent, while lipid levels range from 6.7 to 12.2 percent. The estimated proximate composition of the diets is based on the nutrient composition of the ingredients. Farmers in Chau Doc traditionally use feed formulations 3 and 4 (Table 5) for the initial production phase and feeds 1 and 2 for the final stage of the production cycle. In contrast, farmers in Long

TABLE 5
Farm-made feed formulations for catfish farming in the Mekong Delta (% inclusion rate as fed basis)

Ingredients	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6	Diet 7	Diet 8	Diet 9
Trash fish	20	20	30	35	25				
Rice bran	80	70	50	59	43	40	50	50	50
Broken rice		10	20						
Soybean meal					16	30		20	20
Soybean							30		
Fishmeal					16		20		
Corn								10	
Fish by-products						30		10	
Restaurant waste									30
Vegetable								10	
Brewer's grain				6					
Proximate nutrient composition of farm-made feeds (% dry matter)									
Crude protein	13.6	13.8	14.8	14.1	25.4	24.3	31.5	19.0	21.0
Crude lipid	12.2	11.5	9.9	10.0	9.0	9.8	6.7	9.3	8.0

FIGURE 10
Price fluctuations of the main farm-made feed ingredients in 2005 (US$1.00 = VND 15 800)



Xuyen and Can Tho/Vinh Long prefer to use diets 6 to 9 in which trash fish is completely replaced by soybean meal, fishmeal, by-products of fish processing or restaurant waste. Diets 6 to 9 are relatively high in protein when compared to the trash fish based diets due to the high protein content of soybean meal and fishmeal.

3.5 Price and availability of feed ingredients for farm-made feeds

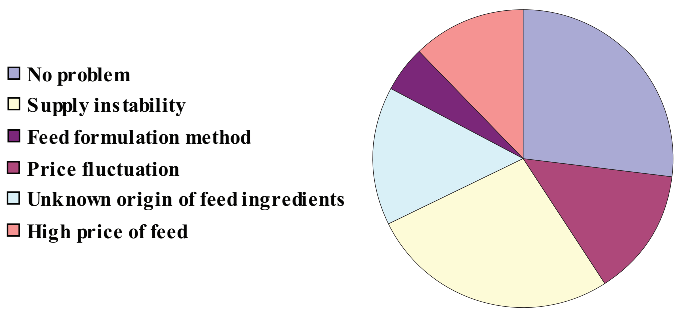
Figure 10 illustrates the price of the five most important feed ingredients. Fishmeal (locally produced with 50 percent protein content) and soybean meal are more expensive than others, though protein content is approximately 3–4 times higher than for trash fish. Hence the use of soybean meal and fishmeal may be more profitable than trash fish in terms of cost per unit of protein. Seasonal price fluctuations are relatively high for trash fish and rice bran but not for soybean meal and fishmeal, which reflects seasonal and general availability. In comparison to other ingredients, trash fish has the highest price fluctuation and this is caused by the seasonal nature of the fishery.

3.6 Future trends in feed use and feeding practices

Constraints

Data in Figure 11 show that more than a quarter (27 percent) of interviewed farmers had no problem with the use of farm-made feeds, though the same proportion of farmers also identified supply instability of the main ingredient (trash fish) as the main constraint in the use of farm-made feeds. Some 26 percent of farmers regarded price and price fluctuation as a constraint. The third most common constraint (voiced by 15 percent of farmers) is the unknown origin and thus unknown quality of feed ingredients. In conclusion, almost all of the constraints revolve around the dependency on trash fish as the main source of protein for farm-made feed preparations.

FIGURE 11
Constraints faced by farmers in the use of farm-made feeds



Future trends in feed use patterns and manufacture

Although farmers face several constraints with respect to the use of farm-made feeds most of them (90 percent) reported that they would maintain their present feeding practices. However, some (10 percent) reported that they plan to change their feed preparations to deal with the scarcity of ingredients. These changes in feed preparation techniques are likely to include the choice of alternative protein sources such as fishmeal and soybean meal and the use of small-scale, on-farm extruders to produce floating pellets.

3.7 Economic evaluation of farm-made and pelleted feeds

Data collected from 48 catfish farmers were used for the economic evaluation of their activities. The analysis is based on a 6–7 month production cycle for both cage and pond farming systems. Farmers normally obtain a loan from a bank for cage or pond construction at an annual interest rate of 8–10 percent. Personal loans may also be obtained from relatives, friends and private lenders but this practice is less common due to their higher monthly interest rates, which may be 2–3 percent higher than bank rates. Other investment costs include capital for a cooker, feed mixer, compressor and a water pump, averaging around US$250–312[3], US$625–940, US$188–250 and US$312–625, respectively and totaling around US$1 750.

Cage culture system

Of the 15 cage farmers, 12 used farm-made feed and three used pellets. Fish stocking densities in cages range from 120–150 fish/m^3, and fingerlings range in size from 80–100 g/fish. Cages are depreciated over a span of 10 years, while other equipment such as feed mixers, extruders, cookers is depreciated over a span of 5 years. The cost per fingerling is in the range of VND 1 000–1 500 (US$0.06–0.09). Two permanent labour units are required if farm-made feeds are used and one unit for pellets. The average food conversions ration (FCR) for farm-made feed ranges from 2.0–3.7 and for pellets between 1.5 and 2. The cost/benefit analysis for cage culture was calculated for a unit of one cubic meter and the results are presented in Table 6.

The results show that the cost of feed accounts for the highest proportion of total production cost in cages (78.8 percent for farm-made feeds and 84.5 percent for pellets). Fingerlings account for the second highest proportional cost, though this is much lower than for feed, at around 8–9 percent. This finding suggests that catfish seed production is no longer a constraint for the catfish farming sector. Labour constituted a small proportion of the total production cost at around 0.9 percent and 1.6 percent for the pellet and farm-made feed systems, respectively.

The results show that the average production cost per kilogramme is higher in the pellet based systems (US$0.64 to US$0.65) than in the farm-made feed systems (US$0.51–0.73). However, because of the highly variable FCRs and the fluctuating price of trash fish it is not possible to conclude that higher profit margins are attained with the use of farm-made feeds.

[3] US$1.00 = 16 000 VND

TABLE 6
Average pangasiid catfish production costs (US$) in cage culture (per cubic meter) (US$1.00 = VND 16 000)

Item	Farm-made feed (n = 12)		Pellet feed (n = 2)	
	Amount	% total	Amount	% total
Fixed cost				
Depreciation (cage, boat, feed mixer and feeding machines)	1.61±1.13	2.41	1.19±0.46	2.44
Variable costs				
Fingerlings	6.58±2.85	9.84	3.58±2.75	7.38
Feed	52.51±0.47	78.55	41.15±0.11	84.69
Labour	1.06±0.99	1.59	0.42±0.03	0.86
Disease prevention and treatment	3.63±2.71	5.42	2.02±0.76	4.16
Fuel and electricity	1.16±0.83	1.74	0.19±0.04	0.39
Interest	0.0		0.0	0.00
Taxes and fees	0.19±0.18	0.29	0.04±0.02	0.08
Transport	1.10±0.01	0.15	0.0	0.00
Total cost				
Per cubic metre	**66.86±29.08**		**48.59±5.27**	
Per kilogramme	**0.62±0.11**		**0.64±0.01**	

Pond culture

The cost benefit analysis for pond based culture was based on data obtained from 34 farmers (Table 7). Stocking density in ponds ranges from 30–40 fingerlings/m^2. The fingerlings used in pond culture are smaller and hence cheaper (US$0.01–0.04) than those used in cages. Average FCRs using farm-made feeds and pellets in ponds are 2.0–3.5 and 1.5–1.7, respectively. Other production costs include fuel, electricity, labour, disease prevention and treatment, interest and transport.

The results show that feed cost accounts for 81 percent and 90 percent of the total production cost for farm-made feeds and pellets, respectively. Feed cost in pond culture is higher than in cage culture. As for cage culture, the cost of seed is the second highest contributor to total production cost.

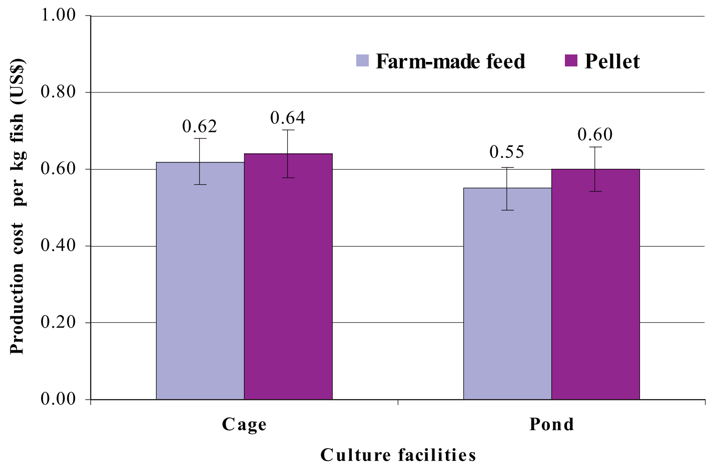
Though there is some variation in the overall production costs between farmers the data indicates that the average production cost is only marginally higher when the fish are fed on pellets (US$0.50–0.69 per kg) in comparison with farm-made feeds (US$0.43–0.64 per kg) (Tables 3 and 4; Figure 12). Overall, it would appear that the cost

TABLE 7
Average pangasiid catfish production costs (US$) in pond culture (per square meter)

Item	Farm-made feed (n = 11)		Pellet feed (n = 23)	
	Amount	% total	Amount	% total
Fixed cost				
Depreciation (pond, boat, feed mixer and feeding machines)	0.15±0.14	0.80	0.19±0.26	0.89
Pond rental	0.00	0.00	0.07±0.04	0.31
Variable costs				
Fingerlings	1.82±2.75	9.81	1.03±0.77	4.82
Feed	15.09±8.48	81.08	19.36±12.08	90.62
Labour	0.18±0.09	0.98	0.18±0.11	0.82
Disease prevention and treatment	1.00±0.61	5.37	0.06±0.85	2.38
Fuel and electricity	1.00±0.07	5.37	0.07±0.15	0.34
Interest	0.0	0.00	0.10±0.01	0.49
Taxes and fees	0.01±0.01	0.04	0.06±0.10	0.27
Transport	0.01±0.02	0.06	0.09±0.04	0.40
Total cost				
Per square metre	18.07±10.63		21.36±0.64	
Per kilogramme	0.55±0.115		0.60±0.10	

of production in ponds is lower than in cages, though this may not be significant. From these data we concluded that farm-made feeds might be a better choice for small-scale farmers. However, large-scale farmers would be advised to use pellets to ensure good stock management and to reduce the risk associated with the instability in trash fish supply.

FIGURE 12
Comparison of production cost in cages and in ponds with farm-made and pelleted feeds



4. CONCLUSIONS AND RECOMMENDATIONS

The survey of 107 fish farmers in the three different locations in the Mekong Delta revealed that feeding practices and culture facilities varied widely with respect to location, culture traditions and feed use practices. Cage culture of pangasiid catfish originated in Chau Doc. Pangasiid farming has now expanded to other locations along the Delta, where pond culture is generally favoured over cage culture. This is ascribed to the lower capital and production costs of pond culture; and perhaps also due to the greater competition for cage space with water borne traffic in Long Xuyen and Can Tho/Vinh Long. It is expected that the trend towards pond culture will soon become the dominant farming practice for pangasiid catfish farming in the Mekong Delta.

Commercially manufactured pellets first became available in 1998 and are now available in most parts of the Delta where catfish farming has developed. Pellets appear to have several advantages over farm-made feeds, though the average production cost per kg is higher than for farm-made feeds. Despite the advantages, farm-made feeds still remain the most popular type of catfish feed in the more traditional farming areas. Moreover, many pellet feeding farmers also use farm-made feeds during the final month(s) of grow-out period. The practice is particularly prevalent when the market price of fish declines. Figures 13 and 14 illustrate the preparation and use of farm-made feeds and pelleted feeds.

Farm-made feed traditionally consists of trash fish and rice bran. In recent years the supply of trash fish in Viet Nam has declined and the resultant higher price of the commodity has had a significant negative impact on aquaculture in the country. The instability in the supply of trash fish has led to the use of alternative protein sources such as fishmeal and soybean meal. Fortunately, recent studies have indicated that *Pangasius* species can be reared entirely on non-marine protein sources without retarding fish growth or survival rates (Hung, 2003).

There are numerous companies in the region that import and distribute ingredients suitable for catfish feed preparation and these are accessible to small-scale farmers. Trash fish throughout the SE Asia region, including Viet Nam, will become even scarcer in future. Hence, to ensure the growth of pangasiid aquaculture in the Mekong Delta there is a need to change the perception of the more traditional farmers, particularly in the Chau Doc area, with respect to the value of alternative ingredients. Farmers in the more recent catfish growing areas are more adaptable to change. Moreover, there is an urgent need for the state to promote and support appropriate on-farm research and extension programmes to assist farmers throughout the Delta to formulate new low-cost feeds and to determine the nutrient requirements of pangasiid catfish.

FIGURE 13
Cooked farm-made feed (top left), cooling of cooked farm-made feed (top right), extruding semi-moist catfish feed (bottom left) and feeding semi-moist, farm-made feed to pangasiid catfish in ponds

COURTESY OF H.P. VIET HUY AND L.T. THANH TRUC

FIGURE 14
Pelleted feed for pangasiid catfish (left) and feeding of *Pangasius hypophthalmus* in ponds (right)

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COUNTRY REVIEWS: AFRICA

Analysis of feeds and fertilizers for sustainable aquaculture development in Cameroon

Victor Pouomogne
Institute of Agricultural Research for Development (IRAD)
Fishculture and Inland Fisheries Research Station, PO Box 255 Foumban
Cameroon

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SUMMARY

Aquaculture is an expanding activity in Cameroon. The availability of high quality fingerlings and feeds has been identified as the most important factors that constrain the development of the sector in Cameroon. The data and information presented here was obtained from the available literature and by interviewing key stakeholders in the sector.

Extensive and semi-intensive earthen pond fish farmings are the two most common aquaculture systems in Cameroon. Most small-scale rural fish farmers practice crib-based, compost aquaculture, without supplementary feeding. These cribs comprise around 10 percent of the pond water surface. A small-scale commercial sector is emerging in the peri-urban areas of Yaounde, Bafoussam and Bertoua. These farmers practise polyculture of Nile tilapia and African catfish in fertilized ponds using chicken manure and single feed ingredients such as wheat bran and cotton seed oilcake. More than 80 percent of the 800 tonne production in 2005 was derived from extensive and semi-intensive farming systems. In 2005, less than 200 tonnes of fish were produced using compounded feeds. There are three major and three smaller industrial animal feed manufacturers in Cameroon. Only one of the larger concerns produces aquafeeds. The total production capacity of animal feed manufacturers is estimated to be over 150 000 tonnes per year, though current production is less than 100 000 tonnes. In addition to the industrial sector, a farm-made livestock feeds sector is currently developing very rapidly in Cameroon, under common initiative groups that are less restricted by taxation policies. Most of the ingredients needed in classical animal compounded feed formulations are available on local markets. The prices of most feed ingredients have been relatively stable, except for maize and soybean products that are mostly imported.

To facilitate the development of the animal feed sector requires a renewed institutional and private sector focus. Its aims should be to provide information for the sustainable production of scarce ingredients such as maize, soybeans and fishmeal and facilitating the procurement of machinery for making and drying pellets using local technology. In particular, the public sector needs to accelerate the revision of import duties and taxes with respect to fuel, animal feed ingredients, fertilizers and machinery. In addition, researchers need to evaluate more of the locally available alternative feed ingredients and fertilizers and to provide farmers with a better comprehension of compost based aquaculture, which remains the most commonly used system.

1. INTRODUCTION

Aquaculture in Cameroon began in 1948. In comparison to other farming activities the sector is under developed. Fortunately, with the assistance of FAO and the WorldFish Center investor interest in the small-scale aquaculture sector is increasing. Seed and feed have been identified as key constraints for the development of the sector in the newly adopted strategic framework for aquaculture development in Cameroon (Moehl, Halwart and Brummett, 2005). As part of this strategy, the government will no longer set production goals, will endeavour to privatise all former public aquaculture stations, will facilitate development through generation and dissemination of technological and marketing information and focus on quality control of private sector seed and feed production. It should be noted that over 90 percent of fish producers in Cameroon are small, rural or peri-urban farmers who lack the resources to purchase costly feed ingredients. They rely mostly on nutrients derived from pond fertilization with organic materials of miscellaneous origins. In recent years the compound feed industry has shown tremendous growth, largely as a consequence of the rapidly expanding broiler chicken industry. Many of the ingredients used in the manufacture of chicken feed are also used for making fish pellets. Table 1 shows the contribution by livestock and fish to the protein requirement of Cameroon. The data show that fish, followed by beef are the two main protein sources for human consumption.

TABLE 1
Livestock and fish production in Cameroon (1998)

Sector	Population (thousand)	% contribution to national animal protein consumption
Cattle	4 846	25
Sheep	2 304	3
Goats	2 949	3
Pig	1 200	7
Poultry	31 000	8
Fish	*	54

*Total amount of fish consumed by Cameroonians was estimated in 2002 at 250 000 tonnes, of which 150 000 tonnes was from capture fisheries, 400 tonnes from aquaculture and the deficit (100 000 tonnes) imported.

Source: DSDSR (2002)

This review is based on secondary-sources of information and data derived from published papers and unpublished reports. Primary data and information were also collected from the field through consultations with professionals in the sector. The information used for this report is considered the most reliable and up-to date (mid December 2005) for Cameroon, even though some may differ from past available official data issued by the Department of Fisheries (MINEPIA), which is responsible for aquaculture development in the country.

2. GENERAL OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

2.1 Background

In 1952 the colonial administration built 22 aquaculture demonstration stations to strengthen the sector and by 1960 the number of private earthen fish ponds exceeded 10 000. Soon after independence in 1960 the extension effort collapsed and most ponds were abandoned. During the early 1970s a UNDP/FAO regional project increased the number of public aquaculture stations to 32. However, declining donor support and the transfer of aquaculture from the Forestry Department to the Livestock Department weakened the revival. Since 1980 there has been a revival in focussed donor support for aquaculture. The USAID common carp farming project in the Western Highlands (1980–1984, and PCV till 1998), the IDRC provided support for integrated fish cum pig and chicken farming from 1986 to 1990, the Belgian Cooperation Agency provided support for catfish seed production at the Foumban Research Station from 1990 to 1994, the French cooperation agency provided support for participatory aquaculture development in the Yaoundé region from 1994 to 1997, while DFID supported a participatory WorldFish Center project from 2000 to 2005.

The development of aquaculture in Cameroon since independence was therefore largely driven by donor support. Given the stop-start, top-down nature of support the evolution of the sector until the mid 1990s has been erratic. In 1995, after evaluating

TABLE 2
Aquaculture production (tonnes) in Cameroon (1990–2005)

Species	1990	2000	2003	2004	2005
Nile tilapia	80	180	250	350	450
North African catfish	6	120	180	230	300
Others	20	50	70	70	70
Total	**106**	**350**	**500**	**650**	**820**

Source: Author estimates, PNVRA, WorldFish Center, FAO Cameroon, CEPID and SEAPB (personal communication)

past experiences, the Cameroon Government promoted a more participatory approach such as those supported by the French Cooperation Agency and DFID. This has resulted in considerable changes in aquaculture practices, improved use of local knowledge and practical experience at the farm and village level. In addition, the revision of legislation regulating freedom of associations (1992) and increases in fish prices related to the devaluation of the CFA franc[1] in 1994 have created an environment favourable for sustainable aquaculture development. Population growth and the concomitant increase in the demand for animal protein have also contributed significantly to the rising fish price. As a consequence, many abandoned ponds have recently been rehabilitated and this has often been done without technical input from the extension services. This positive trend is facilitated by recent changes in policy and linked to the new market economy.

2.2 Major cultured species and production figures

An analysis of available data from the National Research and Extension Program, WorldFish Center, FAO Special Program for Food Security and the Department of Fisheries revealed that by the end of 2004 there were approximately 4 000 farmers with 7 000 ponds (>50 percent new or rebuilt since 1995) with an average size of 350 m². Total fish production from earthen ponds was estimated at 600 tonnes, of which more than 90 percent was produced by small-scale farmers. Nile tilapia (*Oreochromis niloticus*) was the most commonly farmed species, followed by North African catfish (*Clarias gariepinus*). The most common practice is polyculture of Nile tilapia with *Clarias gariepinus* where possible, or with other locally available species such as African bonytongue, *Heterotis niloticus* (local name: kanga), snakehead, *Parachanna obscura* (local name: viper fish), banded jewel fish *Hemichromis fasciatus* (local name: panther fish), common carp (*Cyprinus carpio*) or barbs, *Barbus* spp. (local name: gougeon) (Pouomogne, 2005). Fingerlings of the other species listed above are obtained mostly from the wild.

2.3 Aquaculture practices (size of installations, profitability, farming systems)

Aquaculture in Cameroon is dominated by the use of small ponds with an average size of 350 m² and indirect feeding through compost cribs loaded with organic material (mainly grass and weeds) and kitchen refuse. On average, the compost cribs comprise 10 percent of pond surface area. Average production is around 1 900 kg/ha/year (Pouomogne, field work findings 2004). The most progressive farmers (about 15 percent of the total) who are concentrated mainly around Yaoundé (the capital city), use additional organic fertilizers (dry chicken droppings from commercial chicken farms) or compounded low cost pellets (presently available from IRAD and WorldFish Center pilot feed manufacturing plants). The recent on-farm participatory approaches by the WorldFish Center and FAO have shown that production can be increased to around 9 000 kg/ha/year. A small number of commercial producers (FoodFishCorp and EPA) have attained production levels of 15 tonnes/ha/year. Well managed farms with more than 0.5 ha of water were found to be generally profitable. A recent WorldFish Center study involving a dozen farms around Yaoundé showed that sustainable profits are possible (up to 40 percent internal rate of return), particularly where fish farming was integrated with chickens or pigs (Pouomogne, 2003). However, a recent economic

[1] Cameroon local currency; average value in 2005 US$1.00 = CFAF530

TABLE 3
Differences in structural and price parameters between rural and peri-urban harvest markets in southern Cameroon (n= 84 farms)

Variable	Type of harvest market Peri-urban	Rural	One-tail T-test
Number of buyers in market	25.4 ± 8.96	8.3 ± 7.32	0.0004
Average quantity per sale (kg)	4.1 ± 3.47	2.4 ± 0.76	0.1660
Total quantity marketed per harvest (kg)	89.9 ± 48.7	28.2 ± 23.5	0.0127
Total quantity given as gifts (kg)	55.7 ± 41.2	11.4 ± 9.3	0.0458
Total quantity consumed by household (kg)	50.3 ± 89.6	8.3 ± 6.8	0.3020
Catfish price (CFAF/kg)	2 583 ± 376	1 636 ± 354	0.0000
Tilapia price (CFAF/kg)	1 833 ± 408	1 054 ± 258	0.0000
Mean price all species (CFAF/kg)	1 908 ± 570	1 290 ± 386	0.0053

Source: Brummett (2005)

analysis showed that at the current price of CFAF100 for one 5 g catfish fingerling, most small-scale rural farmers are losing money, although they would be profitable at a unit fingerling price of CFAF50. Hence there is a need to reduce the production cost of catfish fingerlings. Table 3 summarizes some socio-economic variables of the recently ended WorldFish Center project.

2.4 Aquaculture development policy in Cameroon and future prospects

Compared to other farming activities, aquaculture in Cameroon remains under developed. To address this inadequacy a strategic framework was developed to accelerate the development of the sub-sector. Facilitated by the FAO and WorldFish Center, the framework was approved at the end of 2002 and provides the foundation for the development of a strategic aquaculture plan (Moehl, Halwart and Brummett, 2005). The framework fits within the Development Plan for the rural sector and the poverty alleviation strategic plan currently implemented by the government (DSRP, 2000; DSDSR, 2002).

The strategic framework defines the respective roles of the public and the private sectors and relevant key points are highlighted below:

- The role of government will be largely restricted to the provision and dissemination of information and will be geared towards control of production and market chain activities to reduce hindrances linked to the interaction of various actors in the field and will cease to participate in any direct production activities. The private sector (including commercial and non-commercial producers, investors, NGOs (Non Governmental Organizations), banks, development agencies) will be directly responsible for the development of the sub-sector. Under these conditions, a sharp reduction of current government infrastructure will occur, which in turn provides opportunities for the private sector (e.g. aquaculture stations). Moreover, the framework recognises that previous interest in aquaculture was driven largely by misdirected assistance, inappropriate information and promotion of the activity in unsuitable environments and was therefore mainly artificial. Henceforth, the development of the sector will be driven by market forces. Scarce government resources can then be mobilised to focus on promoting aquaculture in identified high potential zones, using "mobile mixed teams", including senior researchers and multidisciplinary extension technicians. The proposed new dispensation will compel producers to work together through fish farmers' associations and to facilitate information flow within and between associations, their members, and the market.
- The availability of good quality fish seed has historically been a major constraint to aquaculture development. Within the new strategic framework, government will retain the responsibility of progressive training and will aim to provide private fingerlings producers with up-to-date information on seed production

and hatchery management. Moreover, the public service, through its own infrastructure or specialised NGOs acting for the government will be responsible to develop and maintain brood stock to ensure a regular supply of certified and improved genetic material to private fingerling producers.

- Outreach (extension services) in Cameroon, as elsewhere in sub Saharan Africa, remains a major debacle in aquaculture development. Lessons learnt from the past emphasize the effectiveness of specialized technicians providing on-farm support and supervision or through on-farm participatory research. However, the cost of this approach is prohibitive and unsustainable. By contrast, repetitive failures have been registered with generalist extension services providing advice in the field of aquaculture. A compromise should thus be sought, with *inter alia*, the idea of "mobile mixed teams" evoked earlier, or the establishment of technical assistance contracts with specialised NGO partners on the basis of objectively verifiable indicators. In high potential and prioritised zones (e.g. peri-urban areas of large cities such as Yaounde or Douala), government should explore the opportunity of providing high level technical assistance to suitable and specifically identified private producers. In return for this support such commercial producers would be required to lend support to non-commercial farmers.

To ensure the success of the initiatives a multi-disciplinary committee comprised of representatives of major stakeholders is needed to monitor development and revise the strategy on an iterative basis as and when necessary. For some recurrent issues, such as high level education and training, new outreach paradigms or specific regulatory aspects (e.g. fish handling practise, introduction of alien species, pond effluent management, etc), multilateral partners may be needed to better tackle the issues at the regional or sub-regional level rather than at the national level. In addition, the framework tackles some specific questions, including the future of public aquaculture stations. It is suggested that most of these stations be sold or leased to the private sector on the basis of existing laws and procedures on the sale or lease of public property. One or more stations, preferably those in high potential zones, should be maintained by the State for training, research and genetic management of brood stock.

3. REVIEW AND ANALYSIS OF AQUACULTURE FEEDS AND FEEDING

Compounded balanced diets are used only marginally by Cameroonian fish farmers. More than 90 percent of fish producers in Cameroon know nothing about compounded fish pellets. They depend mostly on on-farm resources such as vegetable matter, animal manure and household wastes for pond inputs. Some farmers provide supplementary feed in the form of agro-industrial by-products such as cereal bran, where affordable.

3.1 Fertilizers, feed ingredients and feeds

3.1.1 Seasonal availability, cost, accessibility, nutritional composition

a. Fertilizers and on-farm aquafeeds

The materials described below are used as pond inputs to stimulate natural water productivity. They are normally dumped into the compost crib or are spread over the water surface. Depending on the level of integrated farm activities and the scale of operation most of these materials are available on the farm. These commodities are farm by-products and are free of charge for most small-scale farmers.

Manure (chicken, pig, rabbit, goat, sheep, cattle)

More than 40 million land animals are reared in Cameroon per annum (DSDSR, 2002). Manure production from this standing stock has been estimated to exceed 30 million tonnes per year. This manure is available all year round and is used mostly for vegetable production and for natural fertilization of extensive pastures. These materials are well suited as fish pond fertilization inputs, with dry manure: fish conversion rates varying from 4–6 for chicken litter to more than 10 for cattle manure. This variation is related to the C:N ratio of the manure, estimated at about 10:1 and 25:1 for chicken and cattle manure, respectively (ODA, 1986, cited by Pouomogne, 1994).

Laos grass and "marguerite"

Laos grass (*Chromolaena odorata) and* "marguerite" (*Tithonia diversifolia, Leucanthemum vulgare*) are available all year round. Both grasses were tested as compost crib input in small ponds (Yossa, 2003) and are now commonly used in most rural fish ponds. The chemical composition on a dry matter basis is as follows: N= 3.2 percent, P = 0.19 percent, K= 2.3 percent, Ca = 1.1 percent, and Mg = 0.55 percent for *Chromolaena odorata*; N= 3.17 percent, P =0.2 percent, K = 3.22 percent, Ca = 3.5 percent, and Mg = 0.41 percent for *Tithonia diversifolia* (Pouomogne *et al.,* 2005).

*Elephant or napier grass (*Pennisetum purpureum*)*

Napier grass is commonly used by fish farmers, both as compost input and as feed for herbivorous species. A certain degree of competition exists for this material as it is also used as a feed for ruminants and pigs. It grows mostly in fertile wet lands. Availability is restricted to the rainy season, from April to October. *P. purpureun* contains 6 percent crude protein (dry matter basis) and 9 percent ash (Pouomogne, 1994).

*Water lily (*Nymphaea *sp), papyrus (*Cyperus *sp) and water hyacinth (*Eichhornia crassipes*)*

These aquatic weeds are available all year round and also occur in many ponds where they have been voluntarily introduced by the farmer to mistakenly "provide shelter to fish". Unfortunately, and as could have been expected, the plants have covered the entire water surface and pond bottom. No formal composting trials have been undertaken to test these materials as pond inputs. Chemical composition of these materials show lower nutritional content compared to Napier grass (New, Tacon and Csavas, 1994).

Cacao husk, coffee pulp

These by-products are available mainly during the harvesting season from November to February. Total availability in 2000 was estimated at 300 000 and 75 000 tonnes, respectively. Both are used as compost crib inputs and in the dry form can also be used at a 20 percent inclusion rate in tilapia and catfish pellets (Pouomogne, Takam and Pouomogne, 1997; Mvouti, 2001).

Cassava pearls and soaking residues

Cassava is one of the staple foods most commonly consumed by rural farmers within the forest areas of Cameroon. Annual production is estimated at 2 million tonnes (DSDSR, 2002). Before consumption the entire tuber is soaked for 2 to 7 days to facilitate pealing and to decrease the cyanidic toxin component of the tuber. The soaking is commonly performed in fish ponds or nearby small streams. The fertilizing material consists of the abandoned "pearls" and the white juice that is diluted in the water during the soaking process. The recommended application rate for pond fertilization is 10 tonnes cassava soaked per ha per week (Pouomogne, 1994). The nutritional composition of cassava is presented in Table 4.

Other on-farm by-products used as feed or fertilizers

Other on-farm by-products that are used for pond fertilization or as feed include palm oil pressure extraction molasses, sugar cane molasses, bean envelopes, over ripe fruit (papaya, guava, avocado), kitchen wastes, dead animals (mostly chickens and pigs), slaughtered animal viscera, miscellaneous forest fruits and termites. All the above are commonly used on an *ad hoc* basis, though precise application rates have not been determined. The availability of these materials is regular and farmers are now demanding reliable scientific information for greater efficiency. Kitchen refuse appears the most readily available commodity with which to load compost cribs. An average of 1.2 tonnes/household/year is produced in the western Cameroon highlands (Pouomogne, Brummett and Gatchouko, 2004, *unpublished data*). The chemical composition of some of the materials are presented in Table 4.

TABLE 4
Proximate composition (% dry matter basis) and availability of common pond input materials in Cameroon (2005)

Material	Crude protein	Ash	P	Ca	Peak availability
Laos grass (*Chromolaena odorata*)	26	-	0.2	1.1	Everywhere, all year
Marigold/marguerite(*Tithonia diversifolia*)	23	-	0.2	3.5	Nearby roads, all year
Elephant or Napier grass (*Pennisetum purpureum*)	6	17	-	-	Wet and fertile soils, all year
Cassava peelings	7	-	0.1	0.2	Household, all year (Feb–May)
Bean peels	30	-	0.4	0.1	Farm plots, Nov–Feb
Leucaena (whole)	24	7	-	-	Farm plots, all year
Mimosa (*Mimosa pudica*) leaves	30	5	-	-	Farm plots, all year
Groundnut leaves	16	19	-	-	Farm plots, July–Sept
Sweet potato leaves	15	-	0.3	0.4	Farm plots, Nov–Feb
Cassava leaves	27	10	-	-	Farm plots, all year
Taro leaves	17	-	0.2	0.6	Farm plots, all year
Macabo leaves	16	-	12.0	-	Farm plots, all year
Water lily/nenuphar (*Nymphaea sp*)	-	-	-	-	Marsh areas, all year
Water hyacinth	15	-	0.5	0.9	Marsh areas, all year
Papyrus	10	-	-	-	Marsh areas, all year
Ripe avocado fruit	12	-	0.3	0.1	Households, farm plots (March–June)
Ripe guava fruit	11	-	0.2	0.1	Farm plots, all year
Guava leave	9	-	0.1	2.2	Farm plots, all year
Ripe banana peels	10	-	0.2	0.3	Households, farm plots
Ripe banana fruit	7	-	0.1	0.1	Households, farm plots
Papaya fruit	6	-	0.1	0.3	Households, farm plots
Papaya seeds and pulp	27	-	0.4	0.5	Households, farm plots
Papaya peels	18	-	0.2	0.3	Households, farm plots
Ground nut peels	5	2	-	-	Households, farm plots (Jul–Sept)
Kitchen wastes	20	1	-	-	Household, all year
Wild mango (whole)	4	-	0.1	0.3	Household, March–May
Miscellaneous forest fruits	6	-	-	-	All year, Aug–Nov, Southern Cameroon
Palm oil pressure extraction molasses	12	-	-	-	All year
Sugar cane molasses	2	3	-	-	Industrial firm, Bandjock, all year
Dead animals	50	-	-	-	Households and farm plots, all year
Slaughterhouse wastes	52	-	-	-	All year (festivals)
Cow rumen content	60–70	14	-	-	All year (festival)
Termites	-	-	-	-	All year
Snails	61	9.1	-	-	All year
Pig manure	-	-	-	-	Households, southern Cameroon
Cow manure	9	40	-	-	Household and pastures,
Goat/sheep manure	-	-	-	-	Nationwide, all year
Rabbit manure	-	-	-	-	Households, all year
Fresh chicken manure	27	35	-	-	Households

Most of these materials are available free of charge. The main constrains when available are related to collection and transportation cost.

Source: Hauber (2005)

Wood ash and inorganic fertilizers

Wood ash from kitchen fires is occasionally also used for pond fertilization. Inorganic fertilizers are not commonly used in Cameroon small-holder ponds and this is mainly due to the high price of the commodity. In some commercial farms NPK (20:10:10) is the most commonly used fertilizer at an application rate of 50 kg/ha/month to enhance phytoplankton start up, followed by organic fertilization and supplemental feeding.

b. Feed ingredients

The materials discussed in this section are produced by agro-industrial plants. They are used either as single feeds or are compounded with others and fed to fish in the form of dough or pellets, but mostly as dry meal. Feed conversion ratios in semi-intensive pond culture are generally below 8:1 for most of these by-products. Prices fluctuate widely according to supply and government taxes. All of these feed materials are subject to transportation constraints such as bad roads, high transport costs, police harassment and corruption.

Wheat bran

This is a by-product of the wheat flour milling industry. All wheat used in Cameroon is imported. An estimated 30 000 tonnes of wheat bran was produced in 2004. There is a high demand for this relatively low cost commodity, particularly by pig farmers. Given its current price (CFAF60/kg) and the favourable crude protein and gross energy contents (11–16 percent and 18.0 kJ/g respectively), the use of wheat bran as a fish feed has been widely promoted and is now used by most small-scale commercial farmers, alongside with dry chicken layer droppings.

Rice bran

Rice bran production in Cameroon has decreased over the last 15 years. National production in 1990 was estimated at 25 000 tonnes (Fomunyam *et al*., 1990), while current production is less than 10 000 tonnes. Rice bran is used in fish farming in the same way as wheat bran.

Maize

Current national production is estimated at 1.2 million tonnes and there is high user competition for the commodity. The price varies from FCFA75/kg immediately after harvesting in mid July to more than CFAF210/kg in May of the following year. National production does not meet the demand and annually more than 20 000 tonnes are imported. Maize is also used in the manufacture of compound fish diets.

Cotton oil seed cake

The main producer of this ingredient is Sodecoton, a newly privatized firm based in the Northern part of Cameroon. Production in 2004 was estimated at 60 000 tonnes. Its high protein content (49 percent) and relatively low price of CFAF125/kg (2.3 times lower than soybeans) makes it a preferred fish feed ingredient (see formulations in Table 6). Because of the high gossypol content a maximum inclusion rate of 30 percent in compounded fish feeds is recommended (Pouomogne, 1994). Price fluctuations for cotton oilseed cake are negligible.

Groundnut oil cake

Groundnut oilseed cake is another substitute of soybean oilcake in compounded fish feed. It has a similar protein content to soybean oil cake. Current production fluctuates significantly. When available on local markets, it constitutes a good substitute for soybean or cotton seed oilcakes. The price in 2005 of CFAF150–200/kg was lower than for cotton and soybean oilseed cake. Storage of groundnut oilseed cake is problematic.

Compounded feed containing this ingredient is easily contaminated by aflatoxins that can result in high fish mortalities.

Palm kernel cake
This residue of palm kernel oil extraction is one of the cheapest commodities that can be used in compounded fish feeds (CFAF40/kg). About 20 000 tonnes were produced in 2004. The strong smell limits its consumption by most animals and hence the use of the product is minimal. In fish farming, the highest inclusion rate in compounded diets is 10 percent (Pouomogne, Nana and Pouomegne, 1998; Jauncey, 1998).

Soybean oilseed cake
This is the main ingredient used as a protein source in animal feeds in Cameroon. National production of soybean cake is low (<1 000 tonnes in 2004). In 2004, an additional 14 000 tonnes were imported to meet the demand. It is available all year round at a price of just over CFAF300/kg.

Brewery waste
More than 30 000 tonnes of brewery waste is produced annually by the lager breweries. Proximate analysis reveals crude protein = 27 percent, crude lipid = 8 percent, crude fibre = 21 percent, ash = 4 percent and energy = 21.5 kJ/g (Pouomogne, Nana and Pouomegne, 1998). The material is mostly used fresh (75 percent moisture content) as pig and cattle feed and as a pond compost input. It is also used dried and milled in compounded diet for ruminants (cattle, goats, sheep and horses) and in fish feed. At a 20 percent inclusion rate, it also serves as a binder in meat-mincer made fish pellets.

Dry chicken layer droppings
National production in 2004 was estimated at 5 million tonnes. There is a very high demand for chicken manure by peri-urban horticulture and fish farming. It is incorporated in fish pellets (20 percent) and is available all year round, at a price of CFAF60/kg.

Animal meals and additives (oil, minerals, appetizers, binders)
The local fishmeal is mostly derived from milled dry wastes from smoked tilapia, catfish and clupeids (*Sardinella sp* and *Ethmalosa sp*). Fishmeal used by the animal feed industry is imported. In 2005 some 1 000 tonnes were imported and 5 000 tonnes were produced locally. Feed additives, including certain essential amino acids, fatty acids, vitamins, minerals and appetizers, are available on the market as a premix, which is imported for inclusion into chicken feeds.

Other miscellaneous ingredients (coffee bean pulp, cacao husk, Laos grass Chromolaena odorata*, avocado)*
Investigations at IRAD have shown that most of the above ingredients can be incorporated at an inclusion rate of around 20 percent without any significant effect on growth of Nile tilapia in semi-intensive pond culture. Estimated availability of cacao husks and coffee pulp in Cameroon in 2000 was 300 000 and 75 000 tonnes, respectively. Recent investigations have shown that avocado could be incorporated at a level of 10 percent on a dry weight basis into the Standard CP31 diet (see later) for *Clarias gariepinus*. Similarly, a 10 percent inclusion of dry and milled Laos grass in the compounded standard pellet had no significant negative effect on growth and survival of Nile tilapia. Through on-going research the standard pelleted fish feed in Cameroon (CP31 formulation) is continually undergoing least costing changes.

TABLE 5
Protein content, availability and price of major fish feed ingredients in Cameroon (2005)

Ingredient	Crude protein (% dry matter)	Quantity (tonnes/year)	Average price (CFAF/kg)	Peak availability
Crayfish meal	60–76	*	700	Market, all year
Fishmeal (white)	59–66	6 000	600	Feed retailers, all year
Cattle meat meal	50–58	*	600	Sodepa, all year
Blood meal	82–87	*	700	Idem
Concentrate /premix	22	1 000	1 000	Import, retailers
Bone meal (dry powder)	*	*	175	Feed retailers
Groundnut cake	32–40	*	250	Idem, Sodecoton Garoua, CHOCOCAM-Douala
Soybean oil cake	45–49	15 000	360	Import, retailers
Cotton oil seed cake	48–50	70 000	160	Sodecoton, retailers
Brewery waste	18–26	30 000	15	Lager Beer Breweries, nationwide
Wheat bran	12–17	30 -000	50	STC Wheatflour factories Foumbot, Sodeblé Ngaoundere, retailers
Rice bran	8–11	10 000	50	Semry, Soderim, retailers
Maize	8–12	1 200 000	140	Maiscam Ngaoundéré, markets, retailers
Millet (sorghum)	8–12	400 000	150	Idem, Northern Cameroon
Palm kernel oil cake	10–16	20 -000	40	CDC, SOCAPALM, retailers
Cocoa husk	14	300 000	*	Farms plot southern Cameroon (Nov–Feb)
Coffee pulp	11	75 -000	*	Idem, Western highland Cameroon
Dry layer droppings (industrial)	22–28	5 000 000	50	SPC and EPA stores, Nationwide, all year

* Data not available; CHOCOCAM = Chocolaterie de Cameroun; CDC = Cameroon Development Corporation; SOCAPALM = Société Camerounaise des Palmeraies; SPC = Société Camerounaise des Provenderies; EPA = Elevage Promotion Afrique

Source: Hauber (2005) and author estimates

c. Compounded pellets

Four compounded fish diets are currently available in Cameroon. These include a dry mix (usually made by mixing 2 or 3 ingredients), a compound diet made by extrusion through a meat mincer and sun drying the pellets, a commercially available extruded pellet (made by a single manufacturer) and a flake diet made for ornamental fish farming. Most of the feeds contain around 30 percent crude protein, all from plant origin except for the commercially extruded diet, which contains fishmeal. With the development of low-cost formulations using up to 30 percent of non-conventional ingredients, such as cocoa husks and dry chicken manure, the cost price of these pellets vary from CFAF170–250/kg. The retail price varies from CFAF225–500/kg according to demand. The total quantity of pellets used in 2004 was estimated at 100 tonnes. Demand is however increasing and the estimate for 2005 exceeded 300 tonnes. The main aquafeed producer was FoodFishCorp (extruded pellets), while IRAD and most small-scale commercial peri-urban fish farmers produced CP31 and CP45 pellets by alternative means (Pouomogne, Nana and Pouomegne, 1998; Mbongo and Yossa, 2004). Information on the availability, price and crude protein content of the most commonly available fertilizers and feed ingredients are presented in Table 5.

3.1.2 Feeding / fertilization practices (feeding rates, pellet size, feeding frequency)

As indicated earlier, aquaculture in Cameroon is primarily based on a fertilization system using a compost crib built inside the pond. The crib is filled with miscellaneous inputs that are available on the farm. The typical rural/subsistence based farm pond crib is a bamboo frame comprising approximately 10 percent of the water surface area. Prior to stocking the pond, the crib is loaded with weeds and grass and available animal manure. There after, all available household food wastes are dumped into the crib, the contents of which is then turned and mixed biweekly. In this system, fish depend entirely on natural productivity of the water body. Nile tilapia are stocked at an unknown density (usually the left overs of the preceding rearing cycle), and secondary fish species (*Clarias sp.* and/or *Parachanna obscura*) are added when possible to control the tilapia population.

The follow-up to the above scenario is where the farmer aims to commercialize the enterprise. The system is essentially the same as above except that there is a greater degree of controlled management and an improved feeding/fertilization regimen. In such cases stocking density of Nile tilapia is usually 1 to 2 per m^2 plus an equivalent density of *Clarias gariepinus*, *Heterotis niloticus* or *Parachanna obscura,* and farmers are prepared to use scarce animal manure as a pond input rather than for vegetable growing and regularly apply supplementary feeds such as cassava, cocoyam, banana leaves, chopped up dead farm animals, over-ripe fruit and household food leftovers. The feed application rates are not standardized and essentially depend on the availability of the materials.

In close proximity to the main cities of Yaounde and Bafoussam, where farmers have easier access to pond inputs, the second system has evolved further. Peri-urban fish farmers feed their fish directly and no longer rely purely on natural productivity. However, presently the price of feed ingredients is still more important than the nutritional balance of the feed. Among other options, farmers feed their fish with fresh or sun dried brewery waste and wheat bran and water fertility is enhanced mainly by the application of animal manure. Water quality is monitored by way of crude Secchi disks and manure is applied as and when necessary. Some of the peri-urban farmers have livestock pens above their ponds to enhance primary production (Pouomogne, 1994). Pen stocking densities are at a rate of 1 pig (>25 kg weight) or 50 chickens (>3 weeks old) per 100 m^2 water surface.

There are only a few commercial farms where ponds are not fertilized and fish are fed entirely on a balanced diet. Stocking density of fish in intensive systems is higher (up to 3 Nile tilapia + 3 *Clarias gariepinus* + 1 *Heterotis niloticus* per m^2), and ponds are intensively managed. Floating feeding frames are commonly used and the fish are fed according to prescribed feeding tables depending on mean fish weight. The use and practicality of demand feeders is currently being tested by IRAD.

3.2 On farm feed management strategies and pond management techniques

3.2.1 Pond management techniques

Ponds in Cameroon are mostly of the derivation type (receiving water through a feeder canal or pipe). This technology and a minimum water depth of 1.2 m and surface area of 200 m^2, has led to higher fish yields and the increased demand and price of fish has led to pond rehabilitation in many areas. However, the level of management and production depends largely on the means and motivation of the farmer.

a. In rural subsistence based aquaculture the farmer uses left over small fish from the previous rearing cycle. Tilapia are raised either in mono or in poly-culture with a “police fish”. The preferred “police fish” is African catfish, which is stocked at a ratio of 1 predator per 4 m^2. Alternatively indigenous wild species, captured from the surrounding streams, are used and these include native catfish (*Clarias jaensis*), viper fish, panther fish, kanga, gougeon, etc (see corresponding scientific names in the earlier section). Fish are fed with available on-farm materials, including cassava, cocoyam, banana leaves, kitchen refuse, termites, etc. Each pond contains a compost crib and production hardly reaches 3 tonnes/ha/year.
b. In small-scale commercial aquaculture, single feed ingredients are used to feed the fish along with pond fertilization and often integrated with chickens or pigs

reared above the pond water. Pond preparation is performed using quick lime (10 to 30 kg per 100 m² water surface, depending on the nature of the pond bottom and on the farmers understanding of technical recommendations). Normal stocking density is 1 to 2 tilapias plus 1 catfish per m², plus some other fish species at a lower density. Higher production levels have been recorded when the number of species in the pond is increased and the pond is adequately fertilized and fed.

c. Compounded pellets and extruded feeds are commonly used in peri-urban, medium or large commercial farms. Stocking densities are higher at up to 7 fish per m². Strict feeding protocols are maintained, fish are sampled every two months and feed is adjusted accordingly. Production levels of between 9 to 17 tonnes/ha/year have been recorded in some of these systems.

3.2.2 Feed formulation, processing and storage

a. Formulation

Farm made supplemental feed formulations are diverse. Most small-scale commercial farmers use single ingredients to feed fish, based on affordability and seasonal availability. Wheat and rice bran are the two most common single feeds, while farmers around the oil factories use cotton oilseed cake. Other single ingredient feeds for tilapia and catfish polyculture include brewery waste, dry chicken droppings, rotten maize, beans or kitchen leftovers. More innovative farmers use a combination of mixed ingredients either in a dry or a moist form. The available formulated feeds (see Table 6) are used by the more advanced commercial farmers, while the larger companies use formulations as recommended in the international literature (Jauncey, 1998; Guillaume *et al.*, 1999).

b. Processing

The common feed processing practice by small-scale, peri-urban fish farmers consists of sun drying the wet ingredients, milling the dried ingredients in a disk or hammer mills, sieving, mixing and then extruding the mixture through a mincer (2 or 5 mm diameter) after moistening with 30 percent water. The pellets are then sun dried and packaged into 50 kg bags. Sun drying is not possible during the rainy season (i.e. from

TABLE 6
Feed formulations developed in Cameroon for Nile tilapia in polyculture with African catfish and other species

Ingredients	Grower, IRAD CP31 (fertilized ponds)	Grower tilapia 2 (intensive system formula)	Starter, IRAD CP45 (tilapia or *Clarias* below 10 g)
Fishmeal	-	20	55
Soybean meal	13	15	5
Cotton seed meal	15	15	5
Groundnut meal	12	5	4
Brewery waste	10	15	10
Rice or wheat bran	20	15	2
Cocoa husk or coffee pulp	10	-	-
Layer droppings meal	15	-	-
Corn meal	-	8	3
Bone meal	1	-	4
Palm oil	2	2	5
Premix*	2	5	5
Proximate analysis			
Crude protein	28.5	34.5	43.3
Fat	8	9	11
Gross energy (kJ/g)	?	19.2	20.4

*Contains: 50% Met-Lys-Thr-efa-vitamins mix, 25% appetizer (crayfish), and 25% binder (wheat flour)

Source: IRAD and private feed company

April to November in southern Cameroon). At a moisture content above 10 percent pellets become mouldy and unsafe after a few days. An air drying system is currently being tested to address this problem (see Figure 16, Hecht, this volume), because electric, oil or wood dryers are too expensive for small manufacturers. An air dryer of this type with a 100 kg drying capacity costs CFAF100 000. An electric dryer of the same capacity costs 5 to 8 times more. FoodFishCorp produces pellets with an industrial extruder with a capacity of 100 tonnes per month. The ornamental fish feed manufactured in Cameroon is formulated and contains an antioxidant, which plays a key role in the stability of the feed both for nutritive value and for long term storage. After preparing the moist formulation, the mixture is spread in a thin layer, hand pressed using wooden rollers and ultimately pressed between two electrically heated metallic sheets under a precise temperature, pressure and time protocol.

c. Storage

Dried and packed pellets are stored in aerated halls and must be used within four months following manufacture. Formulations containing more than 15 percent groundnut oilseed cake have to be used within two months after packaging.

3.2.3 Feed / fertilizer efficiency and labour cost

Conversion efficiencies for tilapia in polyculture using currently available inputs for crib based systems in rural fish ponds are estimated to range from 8 to 30:1. Most often, labour does not constitute a limiting factor except during the staple crop farming season. Commercial fish farmers who use supplemental feeds show efficiencies 4 to 10 time higher than their rural counterparts. Food conversion ratios of 1.5 to 6:1 have been recorded.

3.3 The development of the aquafeed industry, with special reference to Nile tilapia and African catfish

Aquafeed production in Cameroon remains insignificant and has by no means reached its full potential. Data presented in this section refers mainly to the chicken and pig feed industries.

3.3.1 Overview

The compounded animal feed industry is dominated by the production of chicken feed (70 percent), followed by pig (20 percent) and rabbit feeds. There are three major feed producers (Sodecoton, Société des Provenderies du Cameroun (SPC), Elevage Promotion Afrique (EPA) and several smaller concerns (Complexe Avicole de Mvogt Betsi (CAMB), SABEL, Ets Nkam and GICABAF). In the past SPC and EPA produced about 20 000 tonnes annually (Table 8), however since 2004 both companies have decreased their annual production and now mainly produce feeds for their in-house requirements only.

Soybean oilseed cake is the most important imported feed ingredient (average consumption during the past five years was 11 000 tonnes per annum). The major importers belong to the Chicken Market Chain Syndicate in Cameroon (SIFAC) and these have joined the recent established association for the Defense of Consumer Rights (ACDIC) to fight against subsidised frozen chicken imports from the European Union by the government. All major players oppose the current regulations controlling the animal feed industry. New regulations are under discussion, including the duty free importation of milling equipment and raw materials such as fishmeal, soybean meal, concentrates and other premixes, a five-year tax holiday for new feed millers entering the industry and a code of investment encouraging foreign companies to participate in the Cameroonian animal feed industry (see Moehl, Halwart and Brummett, 2005; MINEPIA, 2005).

TABLE 7
Local and imported animal feed ingredients in Cameroon from 2001 to 2005 (tonnes)

Ingredient	2001	2002	2003	2004	2005*	Origin	Availability**
Soybean oil cake	8 968	12 472	10 824	13 648	7 033	Import	Adequate
Cottonseed oil cake	47 601	50 544	49 119	58 354	63 625	SODECTON	Adequate
Maize "gritz"	8 811	12 022	11 098	10 988	9 067	Import	Poor
Veterinary drugs	126	149	111	124	95	Import	Adequate
Premix	?	1 094	601	22		Import	Adequate
Miscellaneous	4 576	5 724	4 320	4 073	4 011	Import	Excellent

* From January to October 2005
**Precise data on prices were not provided in the reference document.
Source: Groupement Professionnel des acconiers (2005); Sodecoton (pers. comm.)

TABLE 8
Compounded animal feed production in Cameroon

Firm	2000	2001	2002	2003	2004	Capacity tonnes/year	Observations
FishFoodCorp	0	0	0	0	40	1 000	New firm
Sodecoton	28 286	47 601	50 544	49 119	48 354	30 000	Developing
SPC	19 200	18 500	19 000	14 000	18 800	50 000	Strategic changes
EPA	20 600	21 500	14 400	10 800	2 000	25 000	Declining
Ets Nkam	1 900	2 000	2 150	1 800	2 400	5 000	Increasing
CAMB	2 -000	2 500	3 000	3 750	4 000	20 000	Increasing
SIPREK	-	-	-	-	-	15 000	Increasing
SIFAB	-	-	-	-	1 450	12 000	New firm
Total	**71 986**	**92 101**	**87 669**	**79 449**	**75 594**	**131 000**	

Source: Feed company representatives (pers. comm.)

3.3.2 Current feed ingredient imports, exports and taxes

An average of 27 700 tonnes of raw animal feed ingredients were imported annually during the past five years (Table 7).

3.3.3 Total production capacity of compounded animal feeds

The total capacity of the currently active animal feed mills in Cameroon exceeds 100 000 tonnes per annum. However, less than 35 percent of this capacity is currently employed (Table 8).

FishFood Corp focuses on the production of extruded fish pellets, while the other producers manufacture cattle feed concentrate, chicken feed, pig and rabbit and other miscellaneous feeds. Chicken and pig feeds comprise 70 and 20–25 percent of the total feed production, respectively. Major feed producers are committed to technical inspections by larger customers to ensure quality, sustainability and efficiency. This guarantee by the producers is important as many customers are ready to purchase the feeds at higher prices if they have a say and are ensured of quality feeds.

3.3.4 Industrially manufactured versus farm-made aquafeeds

The industrial animal feed manufacturers are facing fierce competition from smaller feed producers. This is mainly a consequence of taxes that favour Common Initiative Groups (GICs) over large corporations. This has provided the impetus for the rapid growth and expansion of smaller feed producers, who only use locally available ingredients. This sector is currently booming at the expense of the larger feed producers, some of which are now forced to limit their production for own use. Moreover, most small-scale commercial fish farmers prefer using the IRAD CP31 pellets made by small-scale producers rather than the extruded products made by FishFoodCorp, despite the fact that the feeds are similarly priced. The preference for the IRAD CP31 feed is mainly a consequence of availability and producers providing a follow-up customer care service.

TABLE 9
Quantity (tonnes) and price (CFAF/kg) of feed ingredients distributed for farm-made animal feeds by the importer ADER from 2003 to 2005

Ingredients		2003	2004	2005	Average
Soybean oil cake	Quantity	6 500	4 820	4 500	5 275
	Price	270	320	250	280
Fishmeal	Quantity	200	184	70	151
	Price	400	433	400	411
Premix	Quantity	65	74	65	68
	Price	1 500	1 440	1 280	1 410

Source: ADER company representative (pers. comm.)

3.4 Problems and constraints

Small-scale commercial aquaculture is developing in Cameroon. However, the majority of farmers remain poor and many cannot afford the shift to a more intensive production system using supplemental feeds. Aquaculture will only be able to play its role in poverty alleviation in the short-term if the compost based traditional system is better understood and optimised. Current problems and constraints in the manufacture and use of aquafeeds in Cameroon can be listed as follow:

- The sustainability of the current demand for aquafeeds is questionable. Most of the demand is derived through subsidized facilitation and from smaller private beginners. Users of formulated aquafeeds are excited by the results obtained but most lack the finances and the necessary business acumen to make fish farming profitable.
- Although data exists on the nutritional value of many alternate ingredients, most locally available materials remain to be appraised, both in terms of palatability and digestibility.
- The tropical climate (high temperature and humidity) negatively affects the quality of ingredients and compounded feeds during storage. For instance, infestation of maize or beans by grain driller insects or oilseed cakes by *Aspergillus* is prevalent throughout Cameroon.
- Funding for research and development in aquaculture is limited and inadequate. When data are available, extension services remain inadequate to diffuse the information reliably to motivated farmers.
- Government taxation policies are disabling the animal feed manufacturing sector. Policies are currently under revision.
- Feed formulation and processing technologies developed in Europe are not always appropriate and research needs to be undertaken to make better use of locally available ingredients such as bloodmeal, fishmeal, soybean meal and binders.
- Aquafeed manufacturing equipment, particularly pelleting machines, are not available locally. Mills and mixers are relatively easily adapted by most local electro-mechanical artisans (Figure 1) but trials with most pelleting system have been disappointing.
- The key constraints are macro-economic policy and climate (devaluation of the currency, the cycles of heavy international debt, corruption, etc) which keep most of sub-Saharan African farmers in an acute state of poverty.
- Lack of expertise in aquaculture technologies. Given the current state of aquaculture in Cameroon it is our opinion that more effort should be focused on the development of semi-intensive pond fertilization based aquaculture, which is more accessible to most Cameroonian farmers. However, this does not mean that the aquaculture feed industry should be neglected.

FIGURE 1
Adapted equipment for the production of fish pellets in Foumban, Cameroon

4. RESOURCE AVAILABILITY AND THE EXPANSION OF THE AQUACULTURE INDUSTRY

4.1 Projected growth

Since 1992, aquaculture has registered a significant growth (Table 2). Many abandoned ponds have been rehabilitated and the work undertaken by various institutions has led to improved aquaculture practices. As already mentioned, most farmers remain relatively poor. However, positive examples of fish farmers who have successfully begun to practice supplemental feeding and who have increased production from 1–3 tonnes to >9 tonnes/ha/year are pushing an increasing number of non-commercial farmers to switch to commercial fish farming. This will generate a continuous increase in aquaculture production. While the larger commercial producers will no doubt increase fish production in Cameroon, we think that the most interesting future prospects will come from small-scale commercial farmers in the peri-urban areas. The most promising of these farmers should be identified and strongly encouraged to participate with development partner organizations. In short, the business is still under construction and in the absence of any commitment from development partners to keep working for some more years to come, it would be unwise to make any projections. The current fact is that for the past 15 years aquaculture in Cameroon has registered a 10 percent yearly growth rate.

5. RECOMMENDATION AND SUGGESTED POLICY GUIDELINES

Semi-intensive and extensive earthen pond-based farming is the prevailing aquaculture system in Cameroon. It has remained a rural subsistence activity up to the mid 1990s. Since then, many changes in living conditions alongside the devaluation of the currency in 1994 have created positive conditions resulting in a revitalization of aquaculture and the mergence of a strong small-scale market orientated aquaculture sector. Development over the last 15 years has been most rapid in peri-urban areas, where there is a greater demand for fish and easier and affordable access to inputs and efficient technical expertise.

The animal feed manufacturing industry has been operating for more than 10 years and produces mainly chicken feed. Most feed ingredients are readily available and prices have remained relatively stable, except for maize and soybeans that are mostly imported. There is a need for government to facilitate the production of maize and soybeans in Cameroon. Whereas most equipment for small-scale animal feed manufactures can be locally sourced at affordable prices, pellet presses and dryers still need to be improved. Government taxation policies constitute a serious hindrance to the development of the sector and the current new legislation under revision is eagerly awaited by animal feed manufacturers. Further scientific work remains to be done on the following: evaluation of alternative locally available feed ingredients and fertilizers; improved performance of pellet drying devices during the rainy season; better storage protocols for aquafeeds; improving the water stability of farm-made pellets and a better comprehension of the natural feed contribution to fish growth within compost based aquaculture systems; Cameroonian farmers need to be educated to optimize natural plus exogenous feed regimens. Moreover, there is need for continued farmer-scientist based partnerships to improve fish breeding and production (Brummett, 2005).

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Analysis of feeds and fertilizers for sustainable aquaculture development in Egypt

Abdel-Fattah M. El-Sayed
Oceanography Department, Faculty of Science
Alexandria University, Alexandria
Egypt

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SUMMARY

Aquaculture is one of the fastest growing animal production sectors in Egypt. During the period 1984 to 2004, production has increased from 15 000 tonnes (9.8 percent of total fish production) to 471 535 tonnes (54.5 percent of total fish production). The rapid growth of the sector is expected to continue due to the availability of aquatic resources and energy inputs, including feed and fertilizer resources.

Aquaculture in Egypt is practiced mainly in semi-intensive and intensive farming systems. Over 85 percent of aquaculture production is obtained from semi-intensive fish culture in brackish-water earthen ponds. Polyculture of Nile tilapia, mullet and carp is the most important semi-intensive culture practice. Nile tilapia contributes over 40 percent of production.

The success or failure of aquaculture depends mainly on the availability and accessibility of inputs, including feeds and fertilizers. However, little information is available on feed and fertilizer resources. The available information indicates that there are no standardised feeding and fertilization schedules. This is particularly important as aquaculture depends mostly on organic fertilization. With the exception of fishmeal and soybean meal, feed ingredients that are commonly used in aquafeeds are available in adequate volumes. However, the prices of most of the ingredients have increased substantially during the past few years.

Poultry manure is the most important organic fertilizer used in ponds. It is estimated that the amount of poultry manure used in aquaculture represents about 3.5–10.0 percent of total poultry manure production. It is expected that poultry manure will remain the major pond nutrient input and hence the proportion of the total poultry manure production used by aquaculture will increase substantially in future. Inorganic fertilizers are rarely used by Egyptian fish farmers and current use represents about 0.01 percent of the national inorganic fertilizer consumption. It is unlikely that there will be any serious competition for fertilizers between aquaculture and agriculture, at least in the short term.

Many factors affect pond fertilization including water quality, soil chemistry, season, pond dynamics, and economics. Pond fish farmers in Egypt rarely consider any of these factors and fertilize their ponds on a "trial and error" basis, in addition to adopting each other's practices. Therefore, fertilization rates and frequencies in many areas are insufficient to produce the required natural food for the fish. Most of the ponds are fertilized only once, just prior to fish stocking and farmers mainly rely on processed commercial aquafeeds (25 percent crude protein) from as early as three days after stocking. This practice could be a costly mistake. In well-fertilized ponds supplementary feeding can be delayed for up to two months resulting in significant savings. As a result of inappropriate feed and fertilization regimes, pond yields are generally low, ranging from 2.5–6.0 tonnes/ha/production cycle (7–10 months).

The commercial aquafeed industry in Egypt is growing at a rapid rate. Current production is about 250 000 tonnes/year, which is about 10 percent of the total animal feed production in Egypt. It is expected that the annual production of aquafeeds will increase to 1.2 million tonnes/year within 10 years. Compressed (sinking) pellets, with a crude protein content of 25 percent, comprise the bulk of the aquafeeds produced in Egypt. Extrusion technology for making floating pellets was introduced in the mid 1990s, and the market for extruded feeds is growing. In contrast, farm-made feeds are rarely used by the Egyptian fish farmers.

The main constraints faced by the farmers and the aquafeed industry include, among others, the escalating price of ingredients, high customs tariffs on feed ingredients, poor handling and storage of feed ingredients and finished feeds, small-scale farmers are unable to access finance, the need for extension services and limited research on fish nutrition, feeding and pond fertilization. Recommendations to address these problems are provided to assist farmers and aquafeed producers to use the available resources in the most sustainable manner and to assist decision makers to adopt best management practices for sustainable aquaculture development in the country.

1. INTRODUCTION

Fish culture has been practiced in Egypt since 2500 B.C. (Bardach, Ryther and McLarney, 1972). The country has about 80 000 ha of brackish-water and freshwater bodies in addition to coastlines of about 1000 km each on the Mediterranean Sea and the Red Sea (Figure 1). These aquatic resources are ample for the sector to expand substantially in future. Between 1995 and 2004, total fish production in Egypt increased by 115 percent from 407 000 to 865 029 (Figure 2). In recent years the Egyptian government has paid particular attention to the aquaculture industry and, as a result, production has increased from 15 000 tonnes in 1984 (9.8 percent of total fish production) to 471 535 tonnes in 2004 (54.5 percent of total fish production). During the same period, capture fisheries only grew by 13.9 percent, from 345 400 tonnes to 393 494 tonnes and over the last five years (2000–2004) capture fisheries have remained more or less static (Figure 2).

The success or failure of aquaculture depends mainly on the availability and accessibility of energy inputs, including feeds and fertilizer resources. This means that the availability of as much information as possible on the source, nature, quantity, quality, prices, seasonality, production, import, export, manufacturers, and distribution of feed and fertilizer among the various users is vitally important for the sustainable development of the sector.

This study reviews the current status and trends of feed and fertilizer use in Egyptian aquaculture. First-hand information was obtained by interviewing farmers and industry representatives and by way of a questionnaire that was distributed among fish farmers and aquafeed manufactures.

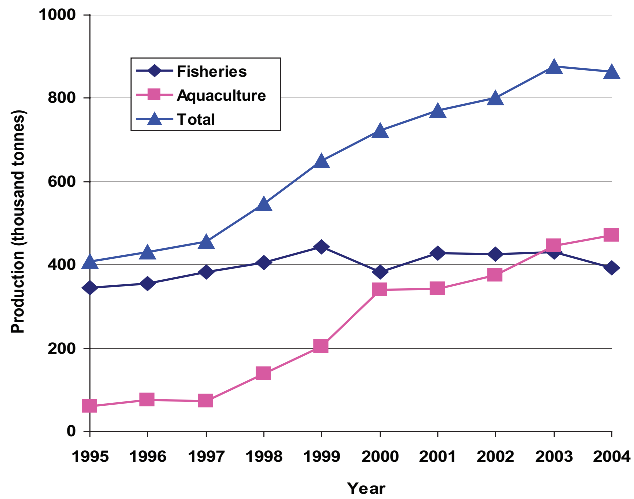
FIGURE 1
Aquatic resources of Egypt

Source: Modified from Hamza (1996)

2. AQUACULTURE PRACTICES AND FARMING SYSTEMS

Aquaculture in Egypt consists of extensive, semi-intensive and intensive farming systems. Fish farms are distributed throughout the Nile Delta region and concentrated mainly in the Northern Lakes areas (Figure 3). The following sections briefly describe the major farming systems and production technologies and Table 1 summarizes the information.

FIGURE 2
Fish production in Egypt during 1995–2004



Source: GAFRD (2005)

2.1 Extensive culture

Traditional extensive farming systems are characterized by low level of intervention, limited use of inputs, low capital investment and poor management. These farms were constructed by reinforcing embankments of natural enclosures, like lagoons, rivers and lakes. The size of these enclosures (hosha) vary from 1–20 ha. Fish (mainly tilapia) are trapped in the hosha and rely on natural food. The net yield from these systems is low and varies from 250–750 kg/ha. This form of aquaculture has been a traditional practice in the northern lakes

FIGURE 3
Major aquaculture production regions in Egypt

Source: Modified from Hamza (1996)

region for many years. The practice has recently been prohibited, because of the destructive effects on lake fisheries and the environment. However, hosha culture is still illegally practiced in some areas and the production from these systems is generally not captured in aquaculture production statistics.

2.2 Semi-intensive earthen pond culture

Semi-intensive fish culture in earthen ponds is, by far, the most important farming system in Egypt. About 86 percent of aquaculture production is obtained from these systems. Semi-intensive fish production has increased from 182 000 tonnes in 1999 to 401 765 tonnes in 2004 (Table 2), although the proportion as a percent of total aquaculture production has remained fairly stable at 87.7–90.5 percent over the same period. Pond culture is practiced mainly by the private sector and consists of many small-, medium- and large-scale farms. The private sector produced 464 320 tonnes in 2004 (98.5 percent of total pond production), whereas the government farms produced 7 183 tonnes (1.5 percent).

TABLE 1
An overview of freshwater and brackish-water aquaculture systems in Egypt, 2005

System	Culture species	Stocking density (fish/ha)	Stocking ratio	Size of pond (ha)	Fertilization and feeding	Rearing period (months)	Harvest size (g)	Total yield (tonnes/ha)
Extensive								
Polyculture	Tilapia, mullets, seabream, seabass, carps, catfish	Natural populations	Varies	5 to over 40	Depends mainly on available natural food, without fertilization	9–14	varies	0.25–0.75
Semi-intensive								
1. Polyculture in brackish-water pond	Tilapia, mullets, carps	15 000–30 000	Varies	0.5–13.0	2–5 tonnes poultry manure + 29 kg super phosphate + 18 kg urea/ ha; 25% CP feed	7–12	200–300 100–200 200–500	5–10
2. Monoculture	Tilapia (mainly all-male)	15 000–30 000		0.5–2.0	2–5 tonnes poultry manure + 29 kg super phosphate + 18 kg urea/ ha; 25% CP feed	7–9	200–400	5–10
Intensive culture								
Monoculture	Tilapia (mainly all-male)	50 000–100 000		0.25–0.50	35–40% CP feeds at the beginning, reduced to 25% CP during fattening	7–10	200–400	15–25
Polyculture	Tilapia + grey mullets	50 000	3:1	0.5–1.0	36% CP feeds at the beginning, reduced to 25% CP during fattening.	9–12	200–300	15–20
Cage culture	Tilapia (mainly all-male)	60–100 fish/m^3		32–600 m^3	35–40% CP feed at the beginning, reduced to 25–30% CP during fattening.	8–14	300–400	25–35 kg/m^3

CP = crude protein

Source: author's field survey

TABLE 2
Aquaculture production (thousand tonnes) in different production systems from 1999–2004

Production system	1999	2000	2001	2002	2003	2004
Rice field	10.0	16.4	18.4	16.3	17.0	17.3
Cage	12.9	16.1	23.7	28.2	32.1	50.4
Pond	182.0	307.6	300.8	331.8	396.1	403.8
Total	204.9	340.1	342.9	376.3	445.2	471.5

Source: GAFRD (2005)

TABLE 3
Aquaculture production (tonnes) by species and production systems in 2004

Species	**Production system**				**Total**	**% of total production**
	FW pond[1]	**BW pond[2]**	**Rice field**	**Cage**		
Nile tilapia	1 920	176 863		20 255	199 038	42.20
Common carp			17 203		17 203	3.60
Mullets (two species)		132 651			132 651	28.10
Carps (bighead, silver and black)		87 674		30 148	117 822	25.00
Gilthead seabream		2 465			2 465	0.52
European seabass		1 812			1 812	0.38
African catfish (*Clarias* sp.)	160	299			459	0.10
Bayad (*Bagrus* spp.)		85				0.02
Total	**2 080**	**401 850**	**17 203**	**50 403**	**471 545**	**100**

[1] Freshwater intensive pond; [2]brackish-water semi-intensive pond
Source: GAFRD (2005)

TABLE 4
Proportion (%) of total production of each species in 2004 by farming system

Species	**Semi-intensive system**	**Intensive system**
Nile tilapia	37.5	4.72
Common carp (in rice field)	3.65	-
Mullet	28.1	-
Carps (bighead, silver and black)	18.6	6.43
Gilthead seabream	0.52	-
European seabass	0.38	-
African catfish	0.1	-
Total	**88.85**	**11.15**

Source: calculated based on total production

Fish ponds vary in size from 0.5–13.0 ha with a depth of 50–150 cm and are stocked at a density of 15 000–30 000 fish/ha. Nile tilapia (*Oreochromis niloticus*), mullets (*Mugil cephalus* and *Liza ramada*) and carp (big head carp, silver carp and black carp) are the major culture species, although tilapia and mullet represent 75 to over 90 percent of the fish in most of the farms in the northern Delata lakes, particularly in Kafr El-Shaikh, Edku, Maadia and Borollus regions. Many farmers in the Central Delta and in Upper Egypt practice polyculture of tilapia and carp. Carp is generally not farmed under monoculture conditions. The contribution by other species, such as seabream, seabass and clariid catfish is minor (Tables 3 and 4). Marine fish such as seabream and seabass are cultured in brackish-water ponds under polyculture conditions with mullet, mainly in Domiat. The ponds used for polyculture of marine fish are generally large (8–20 ha each) and the fish are stocked at relatively low densities (2 500 fish/ha) at a ratio of 6:3:1 (seabass: seabream: mullet, respectively).

Brackish-water and freshwater ponds are generally constructed in depressed irrigated lands or saline lands. Substantial areas of inland lakes, particularly in the northern Delta lakes and Maryut Salt Valley near Alexandria are also enclosed and transformed into production ponds in which fish are produced under semi-intensive, polyculture conditions. Semi-intensive, polyculture in earthen ponds is practiced mainly in brackish-water environments. In 2004, about 85 percent of total aquaculture production originated from brackish-water ponds, while the remainder was produced in freshwater ponds, cages and rice fields (GAFRD, 2005).

Production in semi-intensive systems varies from 5–10 tonnes/ha/production cycle (7–12 months). Monoculture of Nile tilapia is also practiced semi-intensively in many areas (particularly where consumer demand for carp is low). During the period

TABLE 5
Enterprise budget in US$ for a 10-ha semi-intensive pond culture farm in Egypt, 2005

Item	Quantity	Unit cost	Cost (US$/ha)	Cost (US$/10 ha)
Receipts				
Total income	6	1 230	7 380	73 800
Variable costs				
Feed (tonnes)	12	234	2 808	28 080
Seed (x1000 fish)	25	10	250	2 500
Fertilizer (tonnes)	3	20	60	600
Labour (US$/person/cycle)	2	200	200	2 000
Miscellaneous cost (electricity, water, transportation, gas, etc)		600	600	6 000
Fixed costs				
Pond rental		400	400	4 000
Total cost			4 318	43 180
Returns to risk and management			3 062	30 620

Source: author's field survey

1999–2004, the average production in semi-intensive pond culture has increased from 4 to 6 tonnes /ha/year (GAFRD, 2005).

The cost of labour in semi-intensive aquaculture varies between regions. In Kafr El-Shaikh and Behaira, a 10-ha farm requires 2 permanent workers, with a monthly salary of about US$50 per person (US$800–1 000 per 8–10 month cycle) plus an additional cost of about US$100–120/ha for crop harvesting and other seasonal works. Thus, the total labour cost is about US$180–220 US$/ha/cycle (average cost is about US$200). An average budget for a 10-ha semi-intensive pond farm is summarized in Table 5.

2.3 Intensive cage culture

Cage culture is rapidly developing, particularly in the Domiat and Rashid (Rosetta) branches of the Nile River and in the northern Delta lakes region (Lake Manzala and Lake Borullos) (Figure 4). Production from cages has increased from 12 900 tonnes in 1999 to 50 403 tonnes in 2004, and now contributes 10.6 percent of total aquaculture production. Nile tilapia is the principal cage culture species. The sizes of the cages vary from small cages of around 32 m^3 to larger cages of around 600 m^3.

In the larger cages (10x10x6 m), tilapia fingerlings (1–10 g) are stocked at 80–100 fish/m^3 and are initially fed with 35–40 percent CP pellets and then switched over to a 25–30 percent CP pellet for the fattening period, either manually or with automatic feeders. After 10–14 months the fish reach an average weight of 400 g and the final biomass at the end of the production cycle is around 35 kg/m^3. Some farmers stock their cages with larger fish (40–60 g) and in this way are able to reduce the production cycle to 6–8 months.

FIGURE 4
Culture of Nile tilapia in cages in Rashid (Rosetta) branch of the Nile River, near Rashid (left) and in small cages (2–4 m^3) suspended in a drainage canal in a rural area in Behaira Governorate (right)

Smaller cages (2–4 m^3) suspended in drainage canals are also used in rural areas. Stocking densities are lower (20–40 fish/m^3) and agricultural by-products and kitchen wastes are provided as feed. Production in these cages is low (5–10 kg/m^3) but it is still profitable because of the low capital and input costs.

The Egyptian government has recently adopted a policy to promote cage culture of tilapia. The "Social Development Fund" and the Agricultural Development and Credit Bank provide loans for tilapia cage culture enterprises to new university graduates who can not find jobs within the public or private sector. The government funds the feasibility study (free of charge), assists in the construction of cages, site selection, and sometimes provides seed at a subsidised price. Production form theses cages (6x6x2 m) range form 1.5–2.0 tonnes/6–8 month cycle. This programme has been very successful.

2.4 Intensive pond culture

Intensive pond culture is also developing in many areas in Egypt, especially in the newly reclaimed agricultural lands in the desert. Nile tilapia (mainly monosex) is the major cultured species in intensive systems. All male tilapia are produced through oral administration of 17α-methyltestosterone. In these systems fish are stocked at 50 000–100 000 fish/ha and fed with commercial feeds (25–30 percent CP) and reach 200–>400 g in 7–10 months. Some farmers feed the fish with 35–40 percent CP feeds at the beginning and then switch to a 25 percent CP pellet during the grow-out stage.

Intensive polyculture using Nile tilapia and mullet (*Mugil cephalus* and *Liza ramada*) is practiced in Kafr El-Shaikh. Fish are stocked at about 50 000 fish/ha (37 000 tilapia and 13 000 mullet) and fed on commercial pellets. The fish attain 200–300 g after 9–12 months and production ranges from 15–20 tonnes/ha.

2.5 Integrated aquaculture

Rice is widely cultivated in Egypt and integrated rice/fish farming has attracted the attention of many rice farmers in recent years. Fish production (mainly common carp) in rice fields has increased from 10 000 tonnes in 1999 to 17 203 tonnes in 2004 at annual average yields of 300–500 kg/ha (GAFRD, pers. comm.)

In the Kafr El-Sheik Governorate[1] some farmers practice integrated wheat and alfalfa/fish farming, by planting wheat and/or alfalfa in their ponds in winter and flooding them in spring. The crops are not harvested and let to rot in the ponds providing nutrients for fish production. However, more research is needed to investigate this practice.

3. AQUACULTURE FEEDS AND FEEDING

3.1 Major feed ingredients

Fishmeal

Both local and imported fishmeal is widely used in aquafeeds in Egypt. Fishmeal is imported from Denmark, Peru, Chile, Argentina, Norway, Japan, Morocco and Yemen. Imported fishmeal contains 60–72 percent crude protein. Several factors constrain the use of imported fishmeal and these include:

- the price of imported fish meal (65–68 percent CP) has increased from US$591/tonne in 1996 to US$720 in 2004, although this was mainly due to the sharp decline in the value of the Egyptian pound against the US$;
- the increasing demand for fishmeal by aquafeed manufacturers, coupled with shortages on the international market has led to intense competition within the animal feed industry. The rapid expansion of the aquafeed industry in Egypt will intensify the competition for fishmeal and this may lead to further price increases; and

[3] Governorates are the administrative divisions in Egypt. Egypt consists of 26 governorates.

- the quality of fishmeal is often affected by transportation, inadequate storage facilities and distribution.

Local production of fishmeal is negligible. The annual production by a single producer is 200–400 tonnes (Edfina Preserved Foods Company, pers. comm.) and crude protein content ranges form <25–60 percent.

There are no official figures of the volumes of fishmeal used in the aquafeed industry. However, based on the author's questionnaire and interviews it was estimated that about 10 000–20 000 tonnes of fishmeal is currently used by the aquafeed industry.

Shrimp meal

Shrimp meal is locally produced from a small shrimp, which is harvested from brackish-water and coastal lagoons (Port Foad lagoon) near Port Saied. The shrimp is sun-dried, milled, packed and used as a protein source in animal feeds and aquafeeds. The shrimp meal contains about 52 percent crude protein.

Abattoir and poultry by-products

Abattoir by-products, including blood meal, meat meal and meat and bone meal are produced by government abattoirs. Similarly, full-fat poultry by-product meals (consisting of feather, blood, heads, legs and offal) are produced by large-scale poultry production companies These commodities have reasonably good protein levels (50–65 percent CP) and are sold at reasonable prices and are used as partial fishmeal replacers in aquafeeds. The demand for these by-products by the aquafeed industry is not high because of increasing consumer concerns with respect to mad cow disease and other potential health hazards.

Soybean meal

Soybean meal (SBM) is the second most important protein source used by the aquafeed industry, after fishmeal. SBM is imported mainly from the United States of America and Argentina. There is considerable discrepancy as to the volumes of soybean products that are imported. FAO (2006) reported that 927 352 tonnes of soybean products were imported in 2004 (214 893 tonnes of soybeans and 712 459 tonnes of soybean cake), Most of the locally produced and imported SBM is used by the animal feed industry. In 2003, the cattle and poultry industry used 102 755 and 107 986 tonnes of soybean products, respectively (MALR , 2006). In 2003, total aquafeeed production was around 250 000 tonnes (Osman and Sadek, 2004a; Mansour, 2005) and at an average inclusion level of about 20 percent suggests that about 50 000 tonnes of SBM is currently used in commercial aquafeed production.

During the period 1999–2004, local soybean production fluctuated between 10 518 and 43 425 tonnes per annum, but this production was sharply reduced to 25 821 tonnes in 2005 (Table 6). The price of soybean meal increased from US$323/tonne in 1995 to US$462 in 2002 and in 2004 decreased to US$308/tonne, due to the devaluation of the Egyptian pound against the US$.

Cotton seed meal

Cotton seed meal (CSM) is produced mainly in the corticated form (with hulls) containing about 27 percent crude protein. A limited amount of decorticated CSM, containing about 41 percent CP, is also produced. Until recently cotton seed meal was the most important plant protein in aquafeeds, due to its availability and low price. However, due to the sharp decrease in cotton production in Egypt (El-Sayed, 1999, CAPMS, 2006) soybean meal is now the preferred plant protein source. Traditionally cotton oilseed cake was mixed with energy sources (mainly wheat bran or rice bran) and water to form dough that was fed to farmed fish.

TABLE 6
Production (thousand tonnes) of major agricultural crops during 1999–2005

Crop	1999	2000	2001	2002	2003	2004	2005
Wheat	6 564	6 564	6 255	6 625	6 845	7 180	8 144
Rice	5 816	6 001	5 227	6 105	6 175	6 351	6 124
Maize	5 437	5 650	6 094	5 677	5 682	5 842	NA*
Kidney bean	307	354	440	401	337	331	282
Sugar beet	2 560	2 890	2 858	3 168	2 692	2 861	3 430
Sugar cane	15 254	12 697	15 572	16 030	16 246	16 335	16 317
Vegetables[1]	11 963	13 133	12 709	12 561	14 364	13 367	NA*
Cotton	439	483	457	483	481	637	522
Soybean	19.0	11.0	14.9	17.7	28.7	43.4	25.8
Sunflower	20	30	44.1	35.0	31.6	44.3	30.4
Peanut	2 407	2 496	2 734	2 547	2 611	2 552	2 658
Flax seed	10.3	10.9	16.9	19.9	29.0	39.4	14.6

[1]includes tomato, potato, marrow, haricot, kidney bean, pea, cabbage, aubergine, green pepper, okra, sweet potato, lettuce, carrot, cantaloupe and strawberry.
*Not available
Source: MALR (2006)

TABLE 7
Production of major feed ingredients in Egypt in 2004

Ingredient	Production (thousand tonnes)	Value (thousand US$)
Fishmeal	<1	
Soybean meal	43	6 670
Cotton seed meal	300	25 000
Wheat bran	2 000	200 000
Rice bran	130	1 083
Yellow corn	150	22 500
Plant oils[1]	375	312 500

[1]Include cotton seed oil, soybean oil, sesame oil, sunflower oil and corn oil.
Source: CAPMS (2006)

Wheat bran

In 2004, Egypt produced 7.2 million tonnes of wheat. In addition some 6.5 million tonnes were imported from the United States of America, Argentina, Australia and France. Wheat bran production in 2004 amounted to some 2 million tonnes (Table 7). Wheat bran is the most commonly used energy source in animal feeds and in 2003 some 704 263 and 3 991 tonnes were used for cattle and poultry feeds, respectively.

An estimated 50 000 tonnes of wheat bran is currently used per annum in aquafeeds by commercial feedmills and for farm-made feeds. Wheat bran is included at relatively low levels (10–20 percent) in commercial aquafeeds.

Rice bran

In 2004, Egypt produced about 6.35 million tonnes of rice and 130 000 tonnes of rice bran. The seasonal nature of the crop leads to fluctuations in availability and price. A small, although not quantified, quantity is used in aquafeeds.

Maize

In 2004, total maize production was around 5.84 million tonnes of white maize and about 150 000 tonnes of yellow corn. Yellow corn is used mainly by the animal feed industry. In 2003, some 510 000 tonnes of yellow corn was used for cattle and poultry feeds. Egypt imported 2.4 million tonnes of yellow corn in 2004 (Table 8). The commercial aquafeed industry also depends mainly on yellow corn. Inclusion levels range from 30 to 50 percent and it is estimated that about 75 000–125 000 tonnes of yellow corn is currently used per annum in commercial aquafeed production.

Fats and oils

The major plant oils produced in Egypt are cotton seed oil, soybean oil and corn oil, plus some quantities of sesame and sunflower oil. In 2004, some 375 000 tonnes of oils

TABLE 8
Imports and exports of major food/feed commodities in 2004

Commodity	Quantity (tonnes)	Value (thousand US$)	Unit value (US$/tonne)
Imports			
Wheat	4 366 842	727 652	170
Yellow corn	2 429 279	364 817	150
Soybean	214 893	64,508	300
Soybean cake	712 459	214 374	300
Broad (kidney) bean, dry	314,003	93,255	300
Lentils	88,937	43,901	500
Sesame seed	32 095	27 232	850
Sunflower seed oil	115 503	72 461	630
Soybean oil	91 702	55 622	610
Fish oil (2005)	620	16 000	9 920
Vegetable oils	875 169	360 560	421
Fishmeal	15 217	9 118	600
Meat meal	92 534	30 455	330
Cattle offal	13,754	16,826	1 220
Beef and veal, boneless	102 386	180 758	1 770
Exports			
Molasses	406 870	41 279	100
Hydrogenated oils	17 103	13 528	790
Vegetable oils	12 547	10 057	802

Source: FAO (2007)

were produced (Table 7). Because of the downturn in cotton production, Egypt has had to import large volumes of plant oils. In 2004, some 115 503 tonnes of sunflower oil, 91 702 tonnes of soybean oil and 875 169 tonnes of vegetable oils were imported (Table 8). Plant oils are used mainly for human consumption, while only a small amount (about 125 tonnes) is used by the aquafeed industry. Fish oil is not widely used in animal feed and aquafeeds in Egypt due to its high costs. Only about 15–20 tonnes of fish oil are locally produced. However, imported fish oil has jumped from 24 tonnes in 2003 to 620 tonnes in 2005 (Table 8).

Vitamins and minerals
Vitamins and mineral mixtures are mainly imported for livestock and poultry feed manufacturing. A number of national factories are currently producing vitamin and mineral premixes for fish and crustaceans. No data is available on the imports of vitamins and minerals

Additives
Feed additives, including binders, antioxidants, antibiotics, mould inhibitors, enzymes, and chemo-attractants have become essential components in animal and aquafeeds. All are readily available but expensive and their use in animal and aquafeeds in Egypt is limited.

Nutritional composition
The proximate analyses of the major ingredients that are commonly used as feeds or feed ingredients in aquaculture are presented in Table 9.

3.2 Fertilizer resources

Organic fertilizers
Livestock dung and poultry droppings are the main sources of organic fertilizer in Egypt. Livestock manure production (excluding poultry droppings) has increased from 222 million cubic metres (on a wet weight basis) in 1996 to about 300 million cubic metre in 2004. During the same period, poultry manure production has increased from about 1.6 million cubic metres (about one million tonnes) to over 2 million tonnes. It should be noted that a considerable proportion of livestock and poultry is raised by villagers, which is not recorded in the official statistics.

Inorganic fertilizers
Between 1996/7 and 2004/5, production of inorganic fertilizers increased from 3.96 to 11.9 million tonnes (Ministry of Investment, pers. comm., 2005). Fertilizer production and consumption is summarized in Table 10. There are six fertilizer factories in Egypt and production exceeds national demand. Despite the production of nitrogenous fertilizers in excess of demand, there is an annual shortfall during the summer (May to July) and this is due to the requirements for sugar cane, maize and cotton farming.

TABLE 9
Chemical composition (percent as fed basis) of feed ingredients commonly used in animal and fish feeds

Ingredient	Moisture	Crude protein	Crude lipid	Crude fibre	NFE	Ash
Plants and plant by-products						
Green roughages						
Alfalfa (first cut)	86.2	2.1	0.7	2.4	5.9	2.7
Alfalfa (second cut)	85.5	1.9	0.4	3.8	6.4	2.0
Alfalfa (third cut)	73.4	3.7	0.6	7.5	11.5	3.3
Corn plant	78.7	1.5	0.5	4.4	12.7	2.2
Sudan grass (first cut)	85.1	1.3	0.4	4.4	7.2	1.7
Sudan grass (second cut)	71.2	2.6	0.8	7.0	15.2	3.2
Sweet corn (first cut)	92.5	0.6	0.2	2.1	3.8	0.8
Sweet corn (second cut)	77.0	1.9	0.6	5.5	12.7	2.4
Sugarcane leaves	71.1	1.3	0.2	7.7	15.5	4.1
Dry forages						
Alfalfa hay (first cut)	9.1	7.0	0.3	27.7	43.2	12.7
Alfalfa hay (third cut)	10.5	10.0	1.9	27.4	40.5	9.7
Wheat straw	10.2	4.2	1.9	22.2	45.5	16.0
Barely straw	10.2	4.1	1.5	21.8	44.1	18.2
Beans straw	13.9	4.0	0.6	19.0	51.3	11.3
Corn cobs	11.3	2.4	0.3	31.4	51.8	2.9
Grains and legumes						
Wheat	11.1	8.3	1.8	3.8	73.3	1.8
White corn	10.3	9.1	4.8	7.2	67.1	1.4
Yellow corn	7.9	8.3	2.9	2.1	82.5	2.1
Sorghum	11.0	9.2	4.2	2.9	82.7	1.2
Barely	13.2	10.1	1.6	8.2	77.1	3.0
Kidney beans	9.8	28.0	1.0	5.7	50.7	5.5
Soybean meal	13.5	45.5	16.9	7.5	24.6	5.5
Cotton seed meal (with hulls)	7.5	27.1	8.5	21.4	27.2	6.9
Cotton seed meal (without hulls)	7.1	44.4	10.1	5.2	25.7	7.5
Sesame seeds (with hulls)	9.0	30.2	14.4	18.0	20.1	17.4
Lentil seed cake	18.5	13.3	10.7	7.1	35.2	7.5
Rice, broken, polished	9.2	11.0	7.8	1.1	75.9	4.2
Rice bran	10.5	13.0	12.1	10.3	57.2	7.5
Wheat bran, coarse	12.0	11.1	3.6	17.8	63.8	4.3
Wheat bran, fine	12.0	17.1	3.0	9.4	65.5	4.5
Corn gluten	5.9	43.9	3.2	4.4	44.0	3.7
Sugarcane bagasse	3.2	1.3	0.4	51.1	44.5	2.7
Animal by-products						
Blood meal	9.3	81.2	1.0	-	-	5.3
Broken eggs	4.2	34.7	15.0	-	-	25.5
Fishmeal (local)	10.3	65.3	10.5	-	-	16.7
Fishmeal (imported)	9.0	70.0	6.1	-	-	11.6
Animal gelatine	11.4	85.7	3.1	-	-	-
Meat and bone meal	4.6	61.8	6.0	-	-	26.0
Poultry by-product meal	13.0	53.9	23.0	-	-	18.2
Shrimp meal (local)	12.7	51.7	5.6	-	-	26.9

NFE = nitrogen free extract

Source: modified from El-Sayed (1999)

3.3 Agricultural calendar

Understanding the agricultural farming calendar is crucial for aquaculture practices in general and the aquafeed industry in particular. The agricultural cycle in Egypt includes two major cropping seasons; summer crops and winter crops. A third minor season is also exists and known as “Nile crops”. Nile crops are generally summer crops, but the cultivation starts in mid/late summer. The agricultural calendar for Egypt is presented in Table 11.

TABLE 10
Production, consumption, average local sale prices and export of inorganic fertilizers in Egypt in 2004/2005

Fertilizers	Production (tonnes)	Domestic consumption (tonnes)	Average price (US$/tonne)	Export (tonnes)
Nitrogenous				
Urea (46.5% N)	2 390 620	1 707 230	90	663 588
Ammonium nitrate (33.5% N)	1 301 999	1 302 904	91	1600
Ammonium sulphate (20.6% N)	112 507	121 139	84	-
Subtotal based on 15.5% N	10 135 383	8 098 641		1 994 222
Phosphates				
Super phosphate (15% P)	1 360 464	1 160 024	76	191 075
Triple super phosphate (37% P)	33 619	8715	141	26 401
Subtotal based on 15% P	1 443 391	1 181 521		256 197
Grand total	11 578 774	9 280 162		2 250 419

Source: Ministry of Investment (pers. comm.)

TABLE 11
Agricultural cycle and cropping areas (ha) by season in Egypt during 1999–2004

Crops	Farming period	Major crops	Cultivated area (thousand ha)					
			1999	2000	2001	2002	2003	2004
Winter crops	Nov–May	Wheat, alfalfa (barseem), kidney bean, barely, sugar beet, vegetables.	2 546	2 582	2 514	2 592	2 628	2 593
Summer crops	Mar/Apr–Sept	Rice, maize, cotton, Sugar cane, soybean, vegetables.	2 445	2 399	2 506	2 543	2 777	2477
Nile crops	Jun–Oct	Maize, corn, vegetables.	249	259	246	253	259	255
Total			5 240	5 240	5 266	5 388	5 664	5325

Source: CAPMS (2006)

4. THE USE OF FERTILIZERS IN AQUACULTURE

4.1 Organic fertilizers

Semi-intensive fish farming in Egypt depends exclusively on poultry manure for pond fertilization. Fish ponds are fertilized at a rate of 2–5 tonnes/ha. Generally, manure is applied prior to fish stocking (and seldom afterwards). There are no accurate records of the total amount of organic fertilizers used in aquaculture. Given that there are approximately 42 000 ha of fish ponds in Egypt it was calculated that between 70 000–200 000 tonnes of organic fertilizers are used annually for fish pond fertilization. This means that aquaculture annually uses about 3.5–10.0 percent of total poultry manure production. The volumes used are expected to increase as aquaculture expands and as farmers are educated in appropriate manuring practices. At present farmers use between 1.7–4.8 tonnes/ha/production cycle and it is expected that this will increase to over 10 tonnes/ha/production cycle in future.

4.2 Inorganic fertilizer

The use of inorganic fertilizers in Egyptian aquaculture is very limited. About 60 percent of the farmers interviewed use inorganic fertilizers (urea and super-phosphate) in addition to organic fertilizers, but only once at the beginning of the production cycle. Very few farmers apply inorganic fertilizers when natural pond productivity decreases. Super phosphate and urea are applied at 25–36 and 12–24 kg/ha, respectively. It is not known what quantities of inorganic fertilizer are used in aquaculture. Based on the available information it was calculated that about 300–600 tonnes of urea and 625–900 tonnes of super phosphate are currently used for pond fertilization, which if realistic, equates to around 0.01 percent of the total fertilizers used by agriculture. It is unlikely that any competition will arise between agriculture and aquaculture.

5. FARM MANAGEMENT AND FEEDING STRATEGIES

Very little published information is available on aquaculture management in Egypt in general, and feed management strategies in particular. The following section is based on information obtained during interviews with fish farmers and feed manufacturers and analysis of the data obtained from the questionnaires.

5.1 Pond preparation and fertilization

Despite the benefits, minimal attention is generally paid to pond preparation in Egypt, although most of the ponds are drained and remain dry for a long period (3–4 months after fish harvesting). The majority of pond fish farmers harvest their fish in early winter and the ponds remain dry from about December/January to April. In most instances the pond soil is not tilled and/or limed before starting the next production cycle. The information obtained from interviews and the questionnaires also suggest that pond fish farmers rarely adopt scheduled, optimum management practices. Instead most farmers fertilize and manage their systems by trial and error and often adopt each others practices. The general fertilization practice encompasses a single application of 1.5–3.0 tonnes/ha of dry poultry manure. Some farmers supplement this with super phosphate and urea at application rates of 35 and 25 kg/ha, respectively. In general, no fertilizers are applied during the production cycle. Many farmers pile the dry manure on the pond dykes, where it is sprayed with water for a few days before it is washed into the ponds. This process increases the fermentation rate and reduces the time to achieve maximum primary production. In some areas, farmers use cow dung (instead of poultry manure) for pond fertilization. They reported that the large particles of cow manure decay slower than poultry manure and are also consumed by the fish.

As a result of inadequate fertilization rates natural pond productivity is low and many farmers start feeding their fish with commercial feeds (25 percent CP) as early as 3 days after stocking. Abdelghany, Ayyat and Ahmad.(2002) found that when Nile tilapia, common carp and silver carp were reared in adequately fertilized ponds (bi-weekly with 750 kg chicken litter/ha, 100 kg triple super phosphate and 20 kg urea/ha) supplemental feeding could be delayed for up to 6 weeks, without any reduction in fish yield, but with a significant reduction in feed cost. Generally, farmers were found not to be aware of the fact that excessive fertilization leads to significant deterioration in water quality and that this may result in high mortalities, low fish growth (and yield) and economic losses.

Most farmers feed their fish manually twice per day, although the popularity of demand feeders is increasing (Figure 5). In general, the findings revealed that there are

FIGURE 5

Manual feeding of cultured fishes at Barsiq Fish Farm (Behaira) (left) and feeding tilapia with demand feeder at Hamool (Kafr El-Shaikh) (right)

no standard pond management, fertilization and feeding practices. As a consequence, fish yields are generally low compared with well-fertilized, well-fed ponds in other countries. Fish yield range from 2.5–6.0 tonnes/ha/production cycle (of about 7–10 months). There are a few exceptions where yield exceeds 7 tonnes/ha/cycle.

5.2 Cost-benefit analysis of pond fertilization

One of the four goals of pond fertilization is to optimize cost efficiency (Knud-Hansen, 1998). This objective is of crucial importance within the framework of the present report, because fertilization strategies are very often evaluated simply in terms of their ability to enhance growth and production, without any consideration of cost-efficiency. It is critically important that extension workers and researchers consider economic as well as ecological implications when recommending pond fertilization strategies (Knud-Hansen, 1998). Unfortunately, these factors are generally not considered in Egypt. Hence, there is a need for detailed research on fertilization regimens such that rural farmers, who generally have very little education and are ignorant of the economic implications of their management practices, can maximize their returns.

5.3 Farm-made feeds

Although used only by a small number of farmers, farm-made feeds are generally made as follows (El-Sayed, 2006). Ingredients are purchased and sorted to remove impurities or other objects that may damage the manufacturing equipment. The feedstuffs are then milled and mixed according to certain formulations, water is added and the compounded ingredients are cooked or steamed with starch as a binder. Moist strands are extruded using a meat mincer, whereupon the strands are sun dried, broken up and stored. The dry concentrate can also be fed to fish by filling jute bags and suspending these in the water column, or alternatively moist feed balls are made and fed to the fish.

Up to a few years ago, the majority of Egyptian fish farmers relied on farm-made feeds, by mixing energy sources such as wheat bran, rice bran or ground corn with protein sources (mainly local fishmeal or trash fish) at a 3:1 ratio. The mix was fed manually to the fish either dry or wet. This practice was very common especially among small-scale fish farmers. Other formulations include brackish-water shrimp, trash fish, chopped tilapia (*T. zillii*) and local fishmeal as protein sources and wheat or rice ban as energy sources. However, the availability of commercial aquafeeds at reasonable prices has sharply reduced the dependence on farm-made aquafeeds. The major problems related to farm-made feeds include the need for daily feed preparation, the absence of binders and the consequent loss of nutrients and the absence of basic feed formulations. The ingredients used for farm-made feeds and their inclusion levels vary from one area to another and is mainly determined by availability and price.

6. THE ANIMAL FEED INDUSTRY

In 2004, there were 57 registered animal feed factories (50 private and 7 public companies) in Egypt that manufacture various types of feed (CAPMS, 2004). In addition, there are many registered manufacturers/suppliers of feed additives, concentrates and binders. The animal feed industry, including manufacturing, handling, distribution, importation and exportation of processed feeds and feed components is regulated by law (Law 1498 issued by the Ministry of Agriculture and Land Reclamation in 1996) to ensure feed safety and quality. The animal feed industry in Egypt is mainly geared towards poultry and livestock production. The production capacity and actual production of animal feeds in Egypt during 2000/2001–2002/2003 are compared in Tables 12 and 13, respectively. There is a considerable over capacity and the data show that animal feed mills could increase their production by 797 000 tonnes (65 percent).

TABLE 12
Animal feed production capacity in Egypt during 2000/2001–2002/2003

Type of feed	Year	Public sector		Private sector		Total	
		Quantity (thousand tonnes)	Value (million US$)	Quantity (thousand tonnes)	Value (million US$)	Quantity (thousand tonnes)	Value (million US$)
Livestock feed	2000/2001	1 527.2	209.4	1 525.8	240.8	3 053.0	450.2
	2001/2002	1 286.1	164.6	815.2	111.0	2 101.3	275.6
Poultry feed	2002/2003	978.1	129.4	1 043.6	144.3	2 021.7	273.7
	2000/2001	36.0	7.4	1 293.9	231.8	1 329.9 (523.5)*	239.2
	2001/2002	36.0	8.6	454.6	67.2	490.6 (550.1)*	75.8
Total	2002/2003	36.0	8.0	278.8	91.2	314.8 (451.5)*	99.2
	2000/2001	1 563.2	216.8	2 819.7	472.6	4 382.9	689.4
	2001/2002	1 322.1	173.2	1 269.8	178.2	2 591.9	351.4
	2002/2003	1 014.1	137.4	1 322.4	235.5	2 336.5	372.9

*Values in parenthesis are the poultry feed manufacturers production capacity as provided by the MALR (2005).

Source: CAPMS (2004)

TABLE 13
Actual production and value of animal feeds in Egypt during 2000/2001–2002/2003

Type of feed	Year	Public sector		Private sector		Total		Average price (US$/ tonnes)
		Quantity (thousand tonnes)	Value (million US$)	Quantity (thousand tonnes)	Value (million US$)	Quantity (thousand tonnes)	Value (million US$)	
Livestock feed	2000/2001	646.0	88.4	628.0	99.1	1 274.0	187.5	147.3
	2001/2002	577.0	85.9	738.5	102.7	1 315.5	188.6	143.4
	2002/2003	458.5	59.9	766.7	105.0	1 225.2	164.9	134.6
Poultry feed	2000/2001	7.1	1.5	964.6	172.0	971.7	173.5	189.0
	2001/2002	11.7	2.8	443.3	64.6	455.0	67.4	148.0
	2002/2003	8.1	1.8	272.1	58.4	280.2	60.2	214.7
Total	2000/2001	653.1	89.9	1 592.6	271.1	2 245.7	361.0	160.8
	2001/2002	588.7	88.7	1 181.8	167.3	1 770.5	256.0	143.3
	2002/2003	466.6	61.7	1 038.8	163.4	1 505.4	225.1	149.5

Source: CAPMS (2004)

6.1 Commercial aquafeeds

The rapid expansion of aquaculture in Egypt during the past decade has increased the demand for processed aquafeeds. The number of aquafeed mills has increased from 5 mills producing about 20 000 tonnes/year in 1999 (El-Sayed, 1999) to 18 mills with a current annual production of about 250 000 tonnes (Mansour, 2005; Osman and Sadek, 2004a). Overall, this equates to about 10 percent of the total animal feed production (2.6 million tonnes in 2003, including aquafeed production) in the country. The estimated volume and value of major feed ingredients that are currently used by the aquafeed industry are presented in Table 14.

Because Nile tilapia is the most important aquaculture species in Egypt most of the manufactured feeds are conventional, compressed (sinking) pellets with a protein content of 25 percent. Pellet size ranges from 2–5 mm and the feed is mainly used for semi-intensive culture of tilapia, mullet and carp. A small proportion is also used for intensive, monoculture of tilapia, seabream and seabass, especially in cage culture systems. The formulations of three commercial feeds used in intensive and semi-intensive aquaculture are given in Table 15. Despite the different dietary requirements of the various

TABLE 14
Estimated volume and value of the major ingredients used in aquafeed production in 2004

Ingredient	Quantity (tonnes)	Value (thousand US$)
Fishmeal	10 000	7 290
Soybean meal	50 000	15 397
Yellow corn	100 000	16 045
Rice bran	30 000	7 293
Wheat bran	30 000	6 483
Corn gluten	10 000	1 459
Soybean oil	125	97
Vitamin and mineral premix	75	182

Source: Calculated by the author, based on the percentage of each ingredient in the feeds.

species no specific feeds are made for carp, seabass and seabream. However, niche feeds can be made if required, at a premium.

Particular attention has been paid to the nutritional requirements of Nile tilapia under different culture conditions (see El-Sayed, 2006 for more details). The

TABLE 15
Formulation and percent composition of compressed (25% crude protein) pellets

Ingredient	Extruded (private sector)	Compressed (GAMP*; government mill)	Compressed (GAFRD; government mill)
Soybean meal (44% CP)	19.0	22.0	21.0
Fishmeal (72% CP)	9.0	4.0	5.0
Corn gluten	5.6	3.8	2.0
Local meat meal (65% CP)	-	8.0	11.0
Yellow corn	30.0	41.7	36.0
Rice bran	11.0	10.0	24.3
Wheat bran	24.0	10.0	-
Soybean oil	0.5	0.3	0.5
Fish oil	0.5	-	-
Vitamin and mineral mix	0.4	0.2	0.2
Crude protein	25.0	25.0	25.0
Crude oil**	7.6	7.5	9.0

GAMP = General Authority of Milling and Polishing'; GAFRD = General Authority for Fisheries Resources Development; **calculated, based on the lipid contents of the ingredients.

Source: Osman and Sadek (2004b)

TABLE 16
Recommended levels of different alternative protein sources tested for Nile tilapia under laboratory conditions. Levels tested are a replacement of conventional protein sources such as fishmeal or soybean meal

Protein source	Fish weight (g)	Tested levels (%)	Recommended levels (%)
Animal origin			
Shrimp meal	20	100	100
FS + SBM or MBM, PBM or HFM (1:1)	8	0–75	50–75
MBM + Methionine	0.011	40–50	50
MBM	20	100	100
BM	20	100	<100
HFM	0.01	0–100	66
HFM +/- EAA	4–5	10–50	30
Animal by-products	0.1	0–100	100
Chicken offal	10.8	0–20	20
Oilseed meals			
SBM +/- Methionine	0.8	75	75
Soy protein concentrate	3.2	0–100	100
CSM +/- lysine	20	100	100
Grain legumes			
Corn gluten feed + SBM	30	100	100
Corn gluten + SBM	30	100	100
Aquatic plants			
Azolla (*Azolla pinnata*)	4–40	0–100	<25
Water-net (*Hydrodictyon* sp.)	1	0–100	20
Eleocharis ochrostachys	7	20–40	20–30
Curly pondweed (*Potamogeton* sp.)	14.5	25–50	25
Duckweed (*Lemna*)	14.5	0–50	50
Duckweed (*Spirodela*)	13.9	0–100	30

FM, fishmeal; FS, fish silage; SBM, soybean meal; BM, blood meal; MBM, meat and bone meal; PBM, poultry by-product meal; HFM, hydrolyzed feather meal; CSM, cotton seed meal; EAA, essential amino acids; Met, methionine.

Source: El-Sayed (2006)

recommended inclusion levels of various protein sources in Nile tilapia feeds is summarized in Table 16, while the digestibility of several feedstuffs by this species is given in Table 17.

Extruded (expanded, or floating) aquafeed technology was introduced into Egypt in the mid 1990s with the establishment of a small unit with a production capacity of 500 tonnes/year (El-Sayed, 1999). Since 2001, a number of the established commercial

TABLE 17
Presence of endogenous anti-nutrient factors and protein and organic matter digestibility by Nile tilapia of commonly used feed ingredients

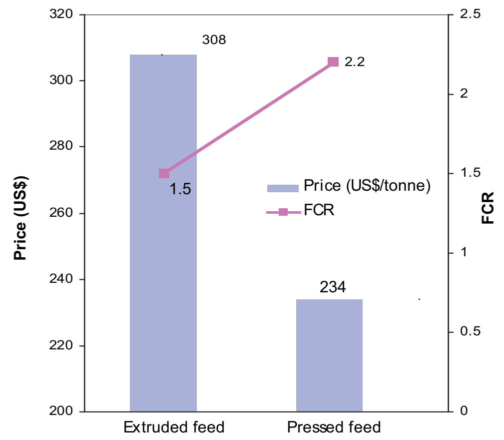
Ingredient	Endogenous anti-nutrients[1]/*	Digestibility (%)**	
		Crude protein	Organic matter
Animal source			
Fishmeal		72–94	58
Sardine meal		87	80
Tuna meal		82	
Anchovy meal		90–94	86
Meat and bone meal		92.2	
Poultry offal meal		74	59
Shrimp meal		87	
Silkworm pupa meal		91.1	
Plant source			
Azolla		75	
Duckweed		88.4–93.9***	78.1–90.7***
Barely	1, 2, 5, 8		
Brewers grains		66	42
Cassava	1, 4		
Cooked cassava meal		74	
Leucaena	23		
Copra meal		56–81	
Corn grain (raw)	1, 5, 8, 13	83	76
Corn grain (cooked)		90	
Corn gluten meal		91–97	
Cottonseed	5, 8, 10, 12, 23		
Cottonseed meal		90	
Cottonseed cake		90	
Groundnut	1, 2, 5, 6, 8		
Groundnut meal		79	72
Rapeseed	1, 3, 5, 7		
Rapeseed meal			
Soybean	1, 3, 5, 6, 8, 11, 12, 14,16, 17		
Soybean meal		91–93	57
Sunflower	1, 7, 20		
Sunflower seed cake		86–89	42
Wheat	1, 2, 5, 8, 11, 18, 22		
Wheat germ meal		95.5	
Wheat middling		76	58
Wheat bran		75	30
Rice	1, 2, 5, 8, 13		
Rice bran	2		
Kidney bean	1, 2, 5, 7, 22		
Sorghum	1, 4, 5, 7, 18		
Lentils	1, 2, 6		
Alfalfa/lucerne	1, 6, 8, 12		

1- Protease inhibitor, 2- Phytohaemaglutinins, 3- Glucosinolates, 4- Cyanogens, 5- Phytic acid, 6- Saponins, 7- Tannins, 8- Estrogenic factors, 9- Lathyrogens, 10, Gossypol, 11- Flatulence factor, 12- Anti-vitamin E factor, 13- Anti-thiamine factor, 14- Anti-vitamin A factor, 15- Anti-pyridoxine factor, 16- Anti-vitamin D factor, 17- Anti-vitamin B_{12} factor, 18- Amylase inhibitor, 19- Invertase inhibitor, 20- Arginase inhibitor, 21- Cholinesterase inhibitor, 22- Dihydroxyphenylalanine, 23- Cyclopropionic acid.

Source: *Tacon (1992); **modified from El-Sayed (2006); ***El-Shafai *et al.* (2004)

FIGURE 6

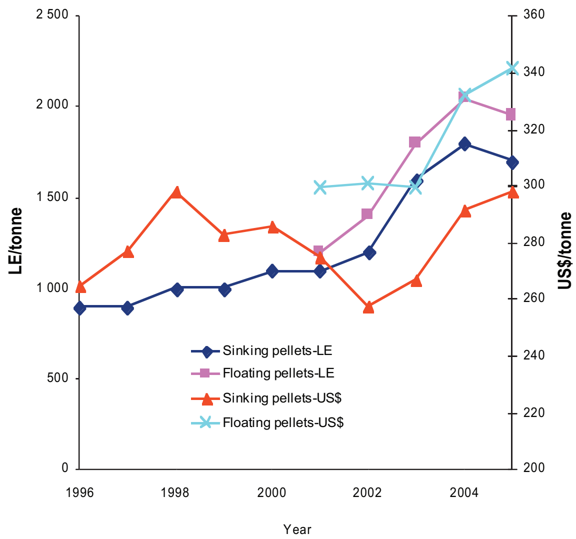
Comparative prices and FCRs of extruded and conventional pressed pellets (25%CP) for Nile tilapia



Source: Osman and Sadek (2004b)

FIGURE 7

Price of extruded and pressed aquafeeds (25% crude protein) from 1996–2005 in US$ and LE



Source: Osman and Sadek (2004b)

feedmills have started production lines for extruded feeds in addition to their traditional production lines. The market for extruded feeds is growing in Egypt, despite the significantly higher price over sinking feeds simply because of better FCRs (Osman and Sadek, 2004b). These findings are illustrated in Figure 6.

Since the mid 1990s the price of compressed pellets (25 percent CP) has gradually increased from about LE[2] 800–900 (about US$250–300) to LE 1800 (US$292)/tonne in 2004 (Figure 7). Similarly, the price of floating (extruded) pellets has almost doubled in the last four years, increasing from LE 1200 (US$295)/ tonne in 2001 to LE 2050 LE (US$332)/tonne in 2004 (Osman and Sadek, 2004b). While the price in US$ has fluctuated little, the increases in LE have been substantial and this is due to the exchange rate of the LE against the US$.

Surprisingly, farmers reported that the price of both sinking and extruded feeds decreased by about 5 percent in 2005, compared with the previous year. They attributed this reduction to increasing competition among manufacturers and a slight increase in the value of the Egyptian pound against the US$ in 2005 (US$1.00 = LE 6.17 and 5.70 in 2004 and 2005, respectively).

The current average FCR using compressed pellets is 2.2:1 (Osman and Sadek, 2004b). Therefore the total amount of manufactured aquafeeds theoretically accounts for 113 000 tonnes of fish or 24 percent of total aquaculture production (471 535 tonnes) in 2004. Hence the bulk of fish production can theoretically be attributed to natural food production in the ponds, through fertilization. From this it can be concluded that organic fertilizers (chicken manure) currently constitutes the most important pond input in Egypt.

7. PROBLEMS AND CONSTRAINTS

The following problems and constraints have been identified:

1. The continuous increase in the price of feed ingredients, particularly imported ingredients such as fishmeal, soybean, corn, oils and additives. This has lead to parallel increases in feed prices.
2. The high custom tariffs and taxes on imported ingredients and manufacturing equipment have contributed to rising feed costs.
3. Because of the rapid growth of aquaculture it is expected that there will be some level of competition for raw materials between the aquafeed and the animal feed industries, which may influence the price of feeds.

[2] US$ = 5.68 LE (Egypt Pound, EGP)

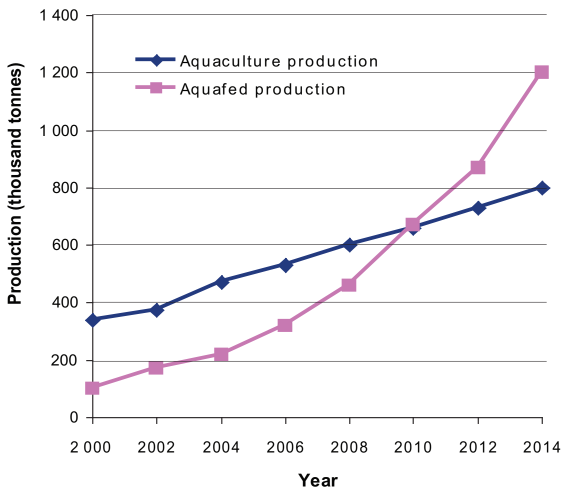
4. The growing public misconception about the use of commercial aquafeeds or farm-made feeds is of concern and must be addressed.
5. One of the most serious problems facing the aquafeed industry in Egypt is the poor handling and sometimes abysmal storage facilities for ingredients and finished feeds.
6. Small-scale farmers are constrained because of the lack of access to finance, which makes them vulnerable to exploitation by suppliers of seeds, feeds, fertilizers. Aquaculture inputs are purchased during the production cycle, but payment is delayed until after the fish are harvested and sold. As a result, farmers are generally supplied with low quality inputs, at high prices.
7. Lack of extension services to advise farmers on pond fertilization, feed formulation and manufacture.
8. Fish farmers are generally unaware of proper fertilization strategies and methods that should be adopted to optimise pond productivity.
9. The limited, and sometimes conflicting, statistical information on feed ingredients, feed production and production capacity. Highly variable values of production, prices, imports, exports, etc, of several ingredients have been reported by different government authorities. This leads to a general mistrust of government statistics and causes confusion among researchers, administrators and decision makers.
10. Limited research on fish nutrition, feeding and fertilization strategies. Key issues pertaining to fish nutrition research and aquafeed technology were identified in an Expert Consultation on Fish Nutrition Research and Feed Technology facilitated by the WorldFish Center in December 2004 in Abbassa (summarized by El-Sayed, 2004).

8. FUTURE PERSPECTIVES

Between 1994 and 2004 aquaculture production has increased 7 fold from 56 600 tonnes to 471 535 tonnes. All indications are that aquaculture will continue to grow in Egypt. The main concerns regarding the future expansion of the sector revolve around the availability and accessibility of inputs and resources. Some aquaculture specialists believe that the future growth of aquaculture will compete with the needs of agriculture, while others discount this scenario. They believe that the continued expansion of the poultry industry in Egypt will lead to the production of greater volumes of manure and that this will compensate for the expected increase in demand for organic fertilizer by aquaculture. In addition, the gradual shift from semi-intensive systems to more intensive production systems will increase the dependence on pelleted feeds, thereby reducing the demand for organic fertilizers. Competition for inorganic fertilizer is also unlikely to occur, at least in the short term. This is simply because the current use of inorganic fertilizers in aquaculture is negligible (about 0.01 percent of total production). In addition, Egypt currently exports substantial amounts of inorganic fertilizers (19 percent of total production in 2004/2005), a small proportion of which would satisfy the needs of aquaculture.

Egypt's aquaculture target is to produce 800 000 tonnes/year by 2014 (Mansour, 2005). This means that aquafeed production is expected to increase to about 1.2 million tonnes/year (Figure 8), assuming a FCR of

FIGURE 8
Projected aquaculture production and feed demand to 2014



Source: Mansour (2005), GAFRD (pers. comm.)

1.5:1 (instead of the current reported value of 2.2:1). It is expected that there will be substantial competition for ingredients by the aquafeed and animal feed industries. Accordingly, the prices of feed ingredients in general and imported ingredients in particular, will increase. Small-scale fish farmers (and small-scale poultry and livestock producers) are likely to be the most seriously affected groups. It is incumbent upon the government to develop action plans to deal with the potential crisis in the animal and aquafeed industries. It is also expected that feed manufacturers will make greater and better use of non-conventional feed resources that are readily available and accessible in Egypt.

9. RECOMMENDATIONS

The following recommendations are made for the sustainable development of aquaculture in Egypt:

- Despite the availability of many conventional and non-conventional feed resources in Egypt, the sustainability, accessibility, prices and nutritional value of these commodities have not been well-studied. This requires urgent attention. Similarly, there is a need to conduct research on the comparative biological and economic advantages of different organic fertilizers, re-evaluation of the protein requirements of the various species under different culture conditions and improving the digestibility of non-conventional, high fibre content feed ingredients.
- Small-scale farmers must be trained to manufacture and encouraged to use farm-made feeds. This will lead to substantial reductions in feed cost and increased farm profitability.
- Greater attention must be paid to feeding and fertilization strategies in semi-intensive culture. Farmers must receive training in pond preparation and management as well as fertilization and feed management.
- Easier access to finance by small-scale farmers must be facilitated by government.
- Custom tariffs on imported feed ingredients (such as soybean, fishmeal and yellow corn) must be reviewed to reduce the price of finished feeds.
- Aquafeed mills should be routinely monitored and inspected to assure that production procedures, feed composition, packaging, handling, transportation, storage and hygiene comply with the quality control standards set by government.
- Extension services should be instituted by the relevant authorities (especially the General Authority for Fisheries Resources Development) to improve feeding, fertilization and farm management.
- The government must undertake periodic reviews of the animal feed legislations to ensure coherency and to reduce/eliminate any overlapping, redundant and conflicting regulations.
- Dialogue among and between producers and distributors of feed or feed ingredients, fish farmers, research institutions and concerned government authorities must be improved.
- The public misconception about the use of commercial aquafeeds or farm-made feeds must be addressed through appropriate educational programmes and the media.

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APPENDIX
Nutritional requirement of aquaculture species

A.1. Dietary protein and lipid requirements (percent of dry feed) of some aquaculture species in Egypt

Species	Life stage	Crude protein	Crude lipid
Nile tilapia	Fry	40–45	10–15
	Fingerlings	35	10
	Growout	25–30	6–9
	Broodstock	40	10
Gilthead seabream	Fingerlings	50–60	15–28
	Growout	45–50	15–22
European seabass	Fingerlings	45–50	10–20
	Growout	40–45	10–-15
Grass carp	Fry	41–43	4
Common carp		3–40	<12

Source: Collected by the author from the literature

Analysis of feeds and fertilizers for sustainable aquaculture development in Kenya

Beatrice Nyandat
Department of Fisheries
PO Box 58187 - 00100 Nairobi
Kenya

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SUMMARY

The expansion of the agricultural sector is crucial for the overall economic and social growth and development of Kenya. In 2003, the sector contributed 24 percent to Gross Domestic Product and a further 27 percent through linkages with manufacturing, distribution and service-related sectors. The agriculture sector, which comprises agriculture, livestock, fisheries and related activities, also supports an estimated 75 percent of the population. In addition, 87 percent of all poor households live in rural areas where farming is their main activity. About 50 percent of Kenyans are food insecure, while significant potential for increased production remains largely unexploited. About 66 of the manufacturing sector is agro-based.

The major cereal crops of Kenya are maize, wheat, rice, sorghum, millet and barley among others. Together with cassava, sweet potatoes and soybeans these crops represent the major food crops farmed in Kenya and there is little or no surplus for the animal feed industry. It is estimated that feed manufacturers use 450 000 tonnes of raw materials annually, of which about 2 200 tonnes of fishmeal is imported from Tanzania. The Kenyan animal feed industry is comprised of a formal and an informal sector. The formal sector is represented by the animal feed manufacturers association of Kenya. There are about 80 registered feed manufacturers in the country of which 17 are considered large scale. At this stage the industry is largely unregulated; hence feed quality is often a major problem. The growth of the fishmeal based animal feeds industry during the last decade has resulted in an unprecedented demand for silver cyprinid *Rastrineabola argentea* (locally known as omena), the second most important commercial fish species in Lake Victoria and Nile perch skeletons as raw material for animal feeds and fishmeal, respectively. It is feared that this will lead to a severe reduction of omena and Nile perch by-products for human consumption.

Approximately a third of Kenya's 5 900 fish farmers are commercial farmers although only four are large scale commercial enterprises. The remainder are rural, non-commercial, small-scale fish farmers. Total fish production is currently estimated at around 1 000 tonnes. Culture systems range across the spectrum from small-scale extensive to semi-intensive pond based polyculture of Nile tilapia, *Oreochromis niloticus* and North African catfish, *Clarias gariepinus* to intensive pond, tank, raceway and cage monoculture.

Though animal manure is generally available its use in small-scale aquaculture is limited. Chicken manure is very expensive and on a unit weight basis approaches the price of chemical fertilizers. This is a major problem. Chemical fertilizers are only used by larger commercial enterprises.

The main protein sources of farm-made feeds are oilseed cakes (cotton, soybean and sunflower), fishmeal, bloodmeal, carcass meal and lake shrimp, though fishmeal is very scarce. Cereal bran, kitchen waste and vegetables are commonly used by the non-commercial farmers. Many commercial farmers, irrespective of scale, have developed their own highly successful formulations and make their own pellets using crude machinery such as meat mincers, while others modify poultry and pig feed formulations. Farm made feeds are fed either as a moist dough, in pellet form or as a dry meal. Only two aquaculture feeds are produced in Kenya, a tilapia pellet and a rainbow trout pellet. These are expensive and hence most commercial farmers compound and manufacture feeds on the farm. Recommendations to address the constraints facing the development of aquaculture are provided.

1. OVERVIEW OF AQUACULTURE PRACTICES

Kenya has extensive bodies of both inland and coastal waters in which aquaculture can be practiced, either on an intensive or extensive scale. Though there are several experimental mariculture initiatives, aquaculture is presently only practiced in inland waters and comprises about 0.6 percent of the total national fish production.

Traditionally, fish farming has mainly been practiced at a subsistence (non-commercial) level. Of the 5 890 registered fish farmers in 2005 only 4 (0.1 percent) were large scale farms, 1 962 (33.3 percent) were small-scale commercial farms and 3 925 (66.6 percent) non-commercial farmers. The increases in production since 1999 have been negligible and official statistics report that approximately 1 035 tonnes were produced in 2004 (Table 1).

TABLE 1
Trends in total fish production and percent contribution by aquaculture to total annual fish yield (1999- 2004)

Year	Total fish yield (tonnes)	Aquaculture production (tonnes)	Aquaculture as % of total fish production
1999	214 712	984	0.46
2000	202 639	967	0.47
2001	164 274	998	0.60
2002	128 227	998	0.78
2003	119 688	1 012	0.85
2004	134 741	1 035	0.77

Source: MLFD (1999–2004)

TABLE 2
Comparison of returns from crop and fish farming in Kenya, 2003

Farming activity	Production (kg/ha/year)	Net annual revenue (US$/ha/year)
Fish (Western Kenya)	7 400	6 420
Fish (Central Kenya)	3 500	4 095
Coffee	2 471	488
Tea	6 000	59 289
Tomato (rain-fed)	9 884	2 604
Tomato (irrigated)	9 884	10 418

Source: Anon (2003)
Average exchange rate (2005): US$1.00 = Ksh75.6

The land tenure system in Kenya curtails land ownership by farmers. Consequently 80 percent of farmers hold small plots of land, normally less than 2 ha. Cultivation of staple and cash crops (mainly tea and coffee for export) forms the backbone of small-holder farming in Kenya. Despite the seemingly higher returns from fish farming (Table 2), farmers pay more attention to crop farming. This may suggest one of two things, either that the calculated returns from fish farming are unrealistic or that farmers are averse to the associated risks of fish farming. Underpinning their activities is a well-developed agricultural research, extension and marketing system. The livestock production sector in Kenya has a well developed extension system with partly privatized veterinary services.

The current development goals of the Kenyan government focus mainly on alleviating poverty, increasing food production and addressing environmental degradation. Since independence, the increase in food production has been below the average population growth rate. Several strategies have been developed to address this, including intensification of existing technologies, increasing the genetic potential of staple and cash crops, developing capture fisheries and livestock production and encouraging the development of large-scale commercial aquaculture.

The choice of aquaculture systems in Kenya is dependent largely on the financial status of the farmer. Several systems are employed and these are listed below:

- intensive pond monoculture of Nile tilapia, *Oreochromis niloticus* and rainbow trout, *Oncorhynchus mykiss*;
- intensive cage culture of Nile tilapia;
- intensive fingerling production of North African catfish, *Clarias gariepinus* (currently there are six commercial catfish hatcheries producing between 10 000 and 20 000 fingerlings per month, mainly as live bait for the long line Nile perch, *Lates niloticus* fishery in Lake Victoria);
- semi-intensive pond monoculture of North African catfish and Nile tilapia (and other tilapia's);
- semi-intensive pond polyculture of North African catfish and Nile tilapia;
- extensive pond monoculture of tilapia and common carp, *Cyprinus carpio*; and
- extensive pond polyculture of Nile tilapia and common carp.

TABLE 3
Aquaculture production statistics (2000-2004), excluding production from Government stations

Indicators	2000	2001	2002	2003	2004
Total no. of farmers	**7 501**	**8 371**	**7 840**	**7 790**	**5 890**
Total area of ponds harvested (ha)	**27.36**	**16.77**	**88.0**	**19.9**	
Tilapia production (weight in tonnes) by small-holder, non-commercial farmers in extensive and semi-intensive systems	31.69	70.31	17.16	*	19.76
Tilapia production (weight in tonnes) by commercial farmers in semi-intensive or intensive systems	42.75	*	33.43	27.78	42.13
Total tilapia production (value in US$)	66 438	85 799	56 474	*	20 405
Catfish production (weight in tonnes) by commercial farmers in semi-intensive system	1.51	*	*	*	8.64
Catfish production value (value in US$)	1 453	*	*	*	5 796
Common carp production (weight in kg) by small-holders in extensive systems	675	*	*	*	*
Common carp production value (value in US$)	725	*	*	*	*
Trout production (weight in tonnes) by commercial farmers in intensive system	3.8	1.8	2.5	*	2.5
Trout production value (value in US$)	23 806	17 235	16 541	*	32 052
Total production (tonnes)	**80.4**	**72.1**	**58.6**	**72.0**	**73.09**
Total value (US$)	**71 738**	**103 034**	**78 872**	**89 434**	**104 291**

* Data not available
Source: MLFD (2005)

Fish holding systems include, earthen or concrete ponds, PVC lined earthen ponds, locally assembled cages, concrete raceways and metal tanks.

Approximately 35 percent of tilapia produced in Kenya is produced in semi-intensive systems, while 65 percent is produced in extensive systems. Aquaculture production statistics are summarized in Table 3. Production of common carp in Kenya has virtually stopped and this is most likely due to consumer preferences.

2. ANALYSIS OF FERTILIZERS AND NUTRIENTS

2.1 Availability and accessibility of fertilizers

Poultry and cattle comprise the bulk of livestock production in Kenya. Table 4 shows that there were 11.4 million head of cattle in 2000 and by 2004 this had increased to 13 million. Poultry production has been fairly stable at around 26 million birds per annum.

The amount of organic manure produced on the basis of the national herd in 2004 was approximately 18.8 million tonnes. However, most of the manure is produced from pastoralism and is therefore not readily available for both agriculture and aquaculture. The bulk of the available manure is used for crop production and only a small, non quantified proportion is used for aquaculture. Most small-scale farmers use "green compost" in pond cribs. Accurate data of the quantity of manure used in aquaculture is lacking. In Kenya, the recommended manuring rate for fish ponds is 500 kg/ha/week.

The most commonly used chemical fertilizers by commercial farmers are di-ammonium phosphate (DAP) and urea. From a nutrient supply perspective these are also the cheapest sources of nutrients in the country. For example, the price for dry chicken manure in 2005 was US$400/tonne compared, to DAP and urea, which sold at an average price of US$470/tonne (Table 5).

TABLE 4
Kenya livestock population (thousand) during 2000-2004

Sector	2000	2001	2002	2003	2004
Cattle	11 445	11 476	11 940	12 531	13 022
Sheep	7 940	7 609	9 289	8 157	10 230
Goat		10 804	11 319	11 947	13 391
Pig	311	333	336	415	380
Poultry	26 292	27 031	27 871	28 283	26 240
Donkey	416	479	521	424	516
Camel	718	819	847	895	1 194

Source: MLFD (2004)

2.2 Fertilizer management strategies

Small-scale, non-commercial farmers fertilize their ponds using the crib or the bag method. The crib comprises about 10 percent of total pond size and is loaded with vegetation that rots and gradually releases nutrients into the water. The crib compost is turned weekly to facilitate nutrient release. Alternatively a gunny bag is filled with 5-10 kg dry chicken or goat manure and tied to a corner of the pond. The bag is shaken frequently (once a week) to facilitate the release of nutrients. One bag is used per 200 m^2 and farmers are encouraged to add manure on a weekly or fortnightly basis.

TABLE 5
Price of organic and inorganic fertilizers in Kenya (2005)

Fertilizer	Cost (US$/kg)
Di-ammonium phosphate (DAP)	0.50
Triple super phosphate (TSP)	0.47
Lime ($CaCO_3$)	0.05
Murate of potash	0.49
Urea	0.44
Calcium ammonium nitrate (CAN)	0.40
Chicken manure (dry)	0.40
Cattle manure	0.13
Pig manure	0.06

Source: Author's survey (2006)

Manuring rate depend on the size of the pond. Maximum recommended application rates are 50 g of dry manure per square metre per week (5 kg/100 m^2/week). Most farmers do not weigh the manure they use in their ponds, but measure turbidity to regulate their manuring schedule by monitoring algal blooms and using Secchi disk depth. Ponds are fertilized when Secchi disk depth exceeds 15 cm.

Chemical fertilizers are only used by commercial farmers who practice semi-intensive aquaculture in ponds. The fertilizer is dissolved in a bucket of water and the solution sprinkled onto the water surface at various localities. Application rates for DAP and Urea are 2 g/m^2/week (15 tablespoonfuls/100 m^2/week) and 3 g/m^2/week (about 30 tablespoonfuls/100 m^2/week), respectively. This combination of DAP and Urea is equivalent to 20 kg N/ha/week and 8 kg P/ha/week. These rates are recommended for warmer areas, whereas in cooler areas half the rate is applied.

To reduce pond acidity, commercial farmers apply agricultural lime to earthen ponds. Lime is applied at a rate of 20 g/100 m^2 for red soil, whereas black cotton soil may require more. One week after application the ponds are filled with water.

3. ANALYSIS OF FEEDS AND FEEDING

3.1 Availability of feed ingredients

As mentioned earlier the major cereals produced include, maize, wheat, rice, sorghum, millet and barley among others, and together with cassava, sweet potatoes and soybeans these crops represent the major food crops farmed in Kenya (Table 6). These crops also form the main staple foods of the population and there is little or no surplus for the animal feed industry (MOA, 2004). It is estimated that feed manufactures use about 450 000 tonnes of raw materials annually, worth about 6 billion Kenya Shillings. Approximately 2 200 tonnes of omena fishmeal[1] is imported from Tanzania to support the local industry (AKEFEMA, 2005). The wheat deficit is imported from Pakistan, Russia and the United States of America (Table 7). Kenya

TABLE 6
Food crop production statistics (2002-2004)

	Production (tonnes)		
Crop	2002	2003	2004
Maize	2 408 596	2 710 848	2 138 639
Rice	45 099	40 502	49 295
Millet	72 197	63 622	50 467
Cassava	746 974	521 975	443 000
Sweet potato	434 774	615 458	571 293
Soybean	*	779	653
Sorghum	115 584	127 215	69 508

*Data not available.
Source: MOA (2005)

TABLE 7
Wheat production and import, 2000-2003

Year	Production (thousand tonnes)	Production (% of total requirement)	Import (thousand tonnes)	Import (% of total requirement)	Total (thousand tonnes)
2000	74	10	636	90	710
2001	82	12	617	88	699
2002	60	10	515	90	575
2003	64	11	502	89	567

Source: MOA (2003)

[1] Fishmeal produced from silver cyprinid *Rastrineabola argentea* (locally known as omena), the second most important commercial fish species in Lake Victoria.

imports 98 percent of its vegetable oil requirement, mostly from Malaysia. The severe shortage of suitable feed ingredients continues to be a serious constraint faced by the animal feed industry (AKEFEMA, 2005).

There are two rainy seasons in Kenya when crops are planted:

- long season (April-July), crop planting takes place from March-April and harvesting is from July-September; and
- short season (October-December), crop planting takes place in October and harvesting is from January to February.

FIGURE 1
Supplementary feeding of tilapia with omena dust mixed with maize bran in Bondo, Western Kenya

COURTESY OF DEVIN BARTLEY

Agricultural by-products most frequently used as single fish feeds or as ingredients for compounded feeds include cereal bran (maize, wheat and rice) and oilseed cakes (cotton, soybean and sunflower). The quality of bran is highly variable and depends on the locality and the method of processing. For example, rice bran from Mwea Rice Factory had a crude protein content of approximately 10 percent (Veverica, Were and Gichuri, 2002), however, after the collapse of the factory, other processors emerged and the rice bran obtained from these processors contained between 3-6 percent crude protein (Liti and Munguti , 2003). It was later observed that processors often mix their bran with milled rice husks thus reducing the protein content. Wheat bran obtained from industrial processors is of a more reliable quality with a crude protein content of 14-17 percent. Nonetheless, all of the materials mentioned above are marketed throughout the country for use as livestock feed, though availability depends on the season, the region and demand.

About 99.9 percent of the small-scale, non-commercial tilapia farmers in Kenya rely primarily on natural pond productivity with some supplementation of agricultural by-products as feed to increase yield (Figure 1). Most of the supplementary feeds are readily available and are not utilized as human food. The price of agricultural by-products and other pond inputs is highly variable on a seasonal and a regional basis and this is illustrated in Table 8 and the average price of common fish feed ingredients or supplementary feeds is shown in Table 9.

Fishmeal, bloodmeal, carcass meal, oilseed cakes and Lake shrimp (*Caridina niloticus*) are the main protein sources in farm-made aquafeeds. Fishmeal, in particular, is a scare commodity. Local production of fishmeal is shown in Table 10. The crude protein level of ingredients is often variable and care should be taken when incorporating

TABLE 8
Regional prices of pond inputs, 2004

Commodity	Price (US$/tonne)					
	Nairobi	Rift Valley	Western Kenya	Nyanza region	Central Kenya	Coastal region
Wheat bran	100	80	90	90	100	120
Maize bran	90	80	90	90	90	90
Rice bran	90	100	100	80	80	90
Cattle/sheep/goat manure	260	10	130	260	130	10
Chicken manure	530	400	400	400	400	360
Pig manure	60	60	60	60	60	60
Lake shrimp	400	330–400	260	200	400	660
Omena fishmeal	660–990	530–660	400–460	360	990	925–1 125

Source: MLFD (2005)

TABLE 9
Price of locally available feed and ingredients, 2004

Ingredient	Cost (US$/kg)
Rice bran	0.08
Maize bran	0.09
Wheat bran	0.13
Brewers waste	0.03
Cotton seed cake	0.26
Groundnut cake	0.40
Blood meal (raw)	0.03
Fishmeal	0.53
Grower mash	0.24
Layer mash	0.24
Dairy meal	0.22
Pig finisher	0.19

Source: MLFD (2005)

these ingredients into feeds. For example, the crude protein content of Lake shrimp varies depending on season, fishing area and handling from 40 to 60 percent. Other high protein resources used on ornamental fish farms and catfish and tilapia hatcheries include liver, egg yolk, *Artemia*, rotifers or other zooplankton and powdered (skimmed) milk.

Vegetable oils from cotton seed and soybeans are the main sources of lipids in fish feeds, while cassava starch is often used as a binder.

Vitamins and mineral premixes are only included in commercially manufactured feeds. The use of pigment enhancing feed additives is restricted to a few ornamental fish producers who use naturally occurring material e.g. carotene from carrots, sweet potato and cassava leaves. However, the qualitative and quantitative use of these materials is not documented. There is no documented use of preservatives in fish feeds in Kenya. The proximate composition of some of the more common supplementary feeds or ingredients is provided in Table 11.

TABLE 10
Fishmeal production and import, 2005

Type	Local Production (tonnes)	Source of raw materials	Price (Ksh/kg)	Import	Cost (Ksh/kg)
Marine	7	Tuna waste (head, tail, bones, skin and gut)	18	Nil	NA
Freshwater	15	Nile perch waste (head, tail, bones, skin and gut)	25	Nil	NA
	15 587	Omena, *Rastrineobola argentea*	30	2 200	110

NA = not applicable

Source: Wananchi Marine Products (K) Ltd, W.E Tilley (M) Ltd and AKEFEMA (pers. comm.)

TABLE 11
Proximate composition of major feed ingredients (percent by weight, as fed basis)

Ingredient	Crude protein	Crude lipid	Crude fibre
Wheat middling	15.0	4.2	7.0
Wheat bran	13.0	3.7	12.0
Maize bran	7.5	6.0	10.0
Maize germ meal, solvent extracted	16.0	1.7	5.5
Maize germ cake, expeller	14.0	14.0	4.3
Maize gluten meal	23.0	5.0	4.0
Molasses (cane)	3.0	-	-
Groundnut oilcake	22.0	14.0	9.5
Soybean oilcake (imported)	45.0	7.5	-
Soybean meal (imported)	50.0	1.4	-
Cottonseed oilcake (imported)	38.0	5.8	18.0
Sunflower seed oilcake (imported)	35.0	14.0	20.0
Rice bran, mechanically extracted	12.0	4.5	-
Brewers dried yeast	45.0	1.2	3.9
Fodder yeast	30.0	-	-
Omena fishmeal	58.0	15.0	0.1
Nile perch fishmeal	53.0	15.0	-
Fishmeal (imported)	58.0	15.0	-

Source: College of Agriculture and Veterinary Sciences, Department of Food Technology and Nutrition (2005, pers. comm.)

TABLE 12
Ingredients of plant and animal origin commonly used as aquafeed in Kenya

Type of ingredients	Form in which fed to fish	Nutritional value	Target fish species
Leaves cassava, arrowroot, sweet potato, *Titonia*	Chopped or whole or added to pellets (dried and ground, inclusion rate of 20–30%).	Excellent source of Vitamins, A, B_1, B_2, C and niacin. Crude protein levels, 4.6%–7.0%. Carotene helps give colour to trout flesh and ornamental fish.	Tilapias, common carp after the leaves have decomposed. Trout to a lesser extent and mainly for carotenoids.
Leaves *Sesbania,* *Leucaena,* *Cassia*	Leaves only, seeds are not used as they are toxic.	Good source of vitamins and protein. Inclusion levels: sesbania-26%, leucaena-20%. Also used as fertilizer. The leaves once decomposed make good compost	Mainly tilapias, other fish benefit from the fertilizer effect.
Cereal by-products Maize bran Rice bran Wheat bran	Fed as is or soaked in fresh blood then dried, ground then pelleted. Can be included in pellets at 50–70% depending on quality of main protein source included e.g. fishmeal.	Good energy source; moderate protein. Maize bran-energy 1 424 kJ/g, CP=11%. Rice bran-energy 1 407 kJ/g, CP=10.9%. Wheat bran-energy 1 344 kJ/g, CP=14–17%.	Tilapias, catfishes, carps.
Maize germ	Fed as is or soaked in blood.	Higher protein than bran; good energy source	Tilapias, carps, catfishes.
Wheat pollard	Very finely ground so often included in pellets; inclusion rate depends on main protein source e.g. fishmeal and can be as high as 60–75%. Rarely fed alone as powder.	Good energy source. CP=13.2%	Tilapias, catfishes, carps. Also a major component of trout feeds.
Oilseed cakes Soybean Sunflower Sesame Cottonseed	Cake made by pressing, contain more fats and less protein than cakes made by solvent extraction.	Excellent protein and energy sources. Can get mouldy or become rancid if improperly stored. CP=45–60%, Lipid=1–7%	Tilapias, catfishes, carps.
Animal waste Slaughter-house waste or animal by-products or fish wastes	Can be put directly into pond. Large pieces should be chopped.	Excellent protein and mineral source. Some kind of animal or fish product are usually good if fish are reared in cages. Rich in vitamin $B_{12.}$ CP=48–50% CL=10–14%	Especially for catfishes and also for tilapias and trout.
Insects termites, white ants locusts, maggots, silkworm larvae	Fresh or dried.	Excellent energy source; high protein. Silkworm- CP=55–75%,CL= 15–30%, Termites (dried)-CP=35.7%, Termites(raw)- CP=38%	Trout, tilapias, catfishes, carps.
Industrial waste: Brewers waste	Wet or dried. Can be put directly into pond.	CP=10.7%	Catfishes

CP= crude protein; CL=crude lipid

Source: Veverica, Were and Gichuri (2002)

Farmers in Kenya use a wide variety of supplementary feeds (Table 12) and these also vary by season and region.

3.2 Feed formulations and manufacturing

Compounded pellets in Kenya are only available for rainbow trout and Nile tilapia (Table 13). From 2000 to July 2004, Lafarge Ecosystems (formally Baobab Tilapia Farm) formulated and made their own feeds and then contracted Atta Kenya Ltd. in Mombasa to make a feed based on their formulation. Unga Limited also produces compounded feeds for Nile tilapia but only for orders of not less than one tonne/year (Table 13).

It should be noted that the diets formulated for pigs and poultry are also successfully used as alternate feeds for Nile tilapia and North African catfish, *Clarias gariepinus*, either as single feeds or mixed with Lake shrimp.

TABLE 13
Trout and tilapia pellet production (2004–2005)

Feed	Production (tonnes)		Cost (Ksh/tonne)	
	2004	2005	2004	2005
Trout pellet (Tamfeeds)	45	45	35 000	41 000
Tilapia pellet, Atta Kenya Ltd.		59	17 000	17 000
Tilapia pellet, Unga Ltd. (made-to-order)	*	*	30 000	30 000

*No orders received during the period

Source: Lafarge Eco Systems, Tamfeeds Limited and Unga Limited (pers. comm.)

TABLE 14
Industrial and farm made fish feed formulations in Kenya

Trout pellets (composition not available)	Industrial tilapia pellets	Farm-made tilapia feed (Western Kenya)	Farm-made catfish feed (Western Kenya)	Catfish feed- (Moi University)	Catfish feed (Sagana Fish Farm)
Fishmeal	Wheat pollard 50%	Fishmeal 40%	Lake shrimp 80%	Fishmeal 50%	Lake shrimp 34%
Wheat pollard	Copra cake 17%	Maize meal 60%	Chicken growers mash 20%	Maize germ 15%	Wheat bran 66%
Soybean meal	Cotton seed cake 17%			Cotton seed cake/ sunflower seed cake 9%	
Wheat bran	Fishmeal 16%			Wheat bran 25%	
Calcium carbonate				Vitamins/salt 1%	
Vitamin and mineral premix	Yes	?	?	Yes	Yes

? = information not available

Source: MLFD (2005)

Knowledge of the nutritional requirements of various fish species and technological advances in feed formulation among the feed manufacturers and the fish farmers has increased considerably. Consequently, the development and use of farm-made and formulated feeds to supplement or to replace natural feeds has made rapid strides. Even though it is claimed in some quarters that there is an abundance of feedstuffs and although farmers and hobbyists are now able to formulate their own fish feeds from locally available ingredients, the cost of these ingredients is often prohibitive.

Most plant protein sources, apart from a few like soybean meal, do not comprise more than 25 percent of the diet. Cotton oilseed cake is included at a maximum of 10 percent (though 5 percent is advisable) due to gossypol and other growth inhibitors. Most commercial farms use cooked soybeans, which can be incorporated at levels as high as 42 percent of the diet. Table 14 shows some of the industrial and farm-made feed formulations that are used in Kenya.

Most feeds used in intensive production systems and in home aquaria are commercially produced dry feeds. These consist of simple mixtures of dry ingredients (mash or meal) to more complex compressed pellets or granules. Pellets are often broken into smaller crumbles. The only pellets produced in Kenya are sinking steam extruded pellets for tilapia and trout.

Semi-moist and wet feeds are made from single or mixed ingredients, such as trash fish (though rarely), cooked legumes, rice bran, maize flour, wheat bran, brewers waste, soybeans, cotton and groundnut oilseed cake, bloodmeal, fishmeal or kitchen waste. After cooking they are shaped into cakes or balls, which are then fed to the fish. These feeds are made by a few farmers especially for feeding catfish.

Farm-made feeds are prepared in various ways (Figure 2). Most farmers begin with milling the ingredients, mixing them to desired formulations, adding warm water to make a moist dough and extruding the dough through a meat mincer. The moist "spaghetti" is chopped into small pellets and these are normally sun dried. Other

FIGURE 2
A feed mill for production of farm-made aquafeed, Kirinyaga District, Central Province (left) and a locally assembled pelletizer at the Sagana fish farm, Kenya (right)

COURTESY OF M. MBUGUA

farmers simply mix the dry ingredients and feed their fish with the mash, without further processing. Ingredients are obtained from feed stores, grocery stores and feed stores as well as from various feed manufacturing companies or millers.

3.3 Feeding practices

The basic feed management options employed in Kenya can be grouped into four categories:

1. Zero input systems: The fish are entirely dependent on natural aquatic productivity. This form of aquaculture is carried out by farmers practicing subsistence fish farming (non-commercial small-holder farmers). Yields range between 0.5 and 1.5 tonnes/ha/year. The majority (67 percent) of fish farmers practice this option and contribute about 27 percent of the total aquaculture production in the country.
2. Enhanced primary production systems: In these systems fertilizers are used to increase natural food production. About 75 percent of fish farmers in Kenya fertilize their ponds to some degree or other, either with organic or inorganic fertilizers.
3. Supplementary feed systems: In these systems an external feed is provided to supplement natural productivity. This type of management is practiced by small-scale commercial fish farmers who fertilize their ponds with organic manure and also feed their fish with milled animal feeds (e.g. growers mash, maize, wheat and rice bran or dairy meal). Farmers who practice this option obtain yields of up to 15 tonnes/ha/year.
4. Complete feed systems: Fish are provided with a "nutritionally complete" diet in pellet or moist dough form. Tilapia pellets contain 25 percent protein and 5 percent lipid. Trout grower pellets contain 38 percent protein and starter crumbles have a crude protein content of 50 percent. Production under these conditions varies between 10 and 80 tonnes/ha/year. In intensive systems, tilapia has the advantage in that they can be fed a prepared feed that includes a high percent of plant proteins, while North African catfish requires some fishmeal in the diet for optimal growth. Complete diets are used in all intensive systems (concrete raceways and circular tanks) as well as in recirculation hatcheries. Complete diets are also used under high density cage culture conditions (e.g. Dominion Farms in Western Kenya). Sagana Fish Farm, in collaboration with Moi University, is actively undertaking research on feed formulations using local ingredients.

In intensive systems, fish are fed twice a day (morning and afternoon) but younger fish are fed more frequently. In semi-intensive systems the fish are fed once daily.

TABLE 15
Feeding frequencies, ration and FCR under different culture systems. All fish in Kenya are fed manually

Culture system	Species	Ration	Feeding frequency	FCR
Intensive	Tilapia (Lafarge Ecosystems)	15 kg/day for 8 000 average weight 100 g fish	Every hour, due to flow-through water system	2:1
	Tilapia in cages (Dominion Farms)	2.2 kg/day for 120 kg fish	2 x per day	2.2:1
	Trout	3.5 kg/day for 50 kg of fingerlings 50 kg/day for 1 ton of fish	Fry are fed hourly till satiation. Mature fish are fed 2/day	2:1
Semi-Intensive	Tilapia	Shrimps/maize meal 0.4 kg/day for 25 kg of fish	1x per day	2:1
	Catfish	0.4 kg/day for 20 kg of catfish	1x per day	2:1
	Gold fish	3 kg/day (5 ,000 fishes)	2x per day (morning & afternoon)	-

Source: Lafarge Ecosystems, Dominion Farms Catfish and Tilapia Farmers in Western Kenya (2005, pers. comm.)

Table 15 provides an insight into fish feeding methods in Kenya under different culture conditions.

3.4 Feed storage

Manufactured feeds as well as farm-made feeds with a high lipid and protein content are highly perishable and should be stored under optimal conditions to minimize losses. Only the larger commercial farms have the appropriate infrastructure for bulk storage of feeds or feed ingredients. There is a need to inform smaller farmers of best feed storage practices.

3.5 Review of the development of the animal and aquafeed industries

The most important and recent developments in the feed manufacturing industry has been the formation of the Association of Kenya Feed Manufacturers (AKEFEMA) in 2003 under the umbrella of the Kenya Association of Manufacturers (KAM), which is the country's leading representative industrial organisation. KAM's mission is to promote competitive local manufacturing in a liberalised market.

Currently, there are about 80 active, registered / licensed small and large feed manufacturers, which use about 450 000 tonnes of raw materials. In 2005, the value of the products used by the animal feed industry was estimated at Ksh 6 billion. Omena (*Rastrineobola argentea*) represents about 6.6 percent of the raw materials by volume, which is equivalent to approximately 30 000 tonnes.

There are 17 large feed manufacturers in Kenya. The feed manufacturers declined to provide the necessary information on the capacity of feed production as they considered this to be confidential and so the exact capacity of feed manufacturers could not be established. Total animal feed production in Kenya during 2004/5 was 466 151 tonnes, with poultry feed comprising 55 percent, pig 7 percent, cattle concentrates 35 percent and 3 percent others such as pet, horse and rabbit feed (see Table 16 for the proximate composition of the major animal feeds).

The "fishmeal-based" animal feeds industry in Kenya was developed

TABLE 16
Proximate composition of the major animal feeds in Kenya

Feed	Composition		
	Crude protein	Crude lipid	Crude fibre
Chick & duck mash/crumbles	18.0	6.0	6.0
Growers mash/pellets	15.5	5.0	6.0
Layers complete meal/pellets	17.0	6.0	6.0
Broiler starter mash/crumble	18.8	7.0	5.0
Broiler finisher mash/pellets	17.5	5.0	4.5
Sow & weaner meal/cubes	17.5	4.5	6.5
Pig finishing meal	15.0	6.0	6.5
Calf early weaner pellets	17.0	5.0	6.5
Young stock meal/pencils	16.0	5.0	6.0
Dairy meal/cubes	15.0	4.0	6.5
Unga tilapia pellet	25.0	5.0	6.0
Tamfeeds trout crumble	50.0	12.0	-
Tamfeeds trout pellet	38.0	9.0	-

Source: College of Agriculture and Veterinary Sciences, Department of Food Technology and Nutrition (2005, pers. comm.)

during the last 10 years. This has generated an unprecedented demand for the second most important commercial fish species in Lake Victoria, whole omena and its dust are used in animal feed production whereas the skeleton of Nile Perch is used for fishmeal production. The development of the animal feeds and fishmeal industry has drastically reduced the quantity of whole omena and skeleton of Nile perch available for human consumption. In a 1997 survey, Abila and Jansen (1997) found that six animal feed manufacturing companies in Kenya were using about 70 percent of the omena catch to manufacture fishmeal, while another two companies were using 60 percent of all Nile Perch skeletons available within the Lake region for fishmeal. This is in sharp contrast to the early 1990s when the entire omena catch was used for human consumption.

The demand for local fishmeal by the animal feed industry cannot be met. This is because the omena and Nile perch fishmeal are high in protein and significantly cheaper than imported fishmeal. It is obvious, therefore, that more and more of the Nile perch skeletons and omena and perhaps other fish products are finding their way into the animal feed industry.

As mentioned previously, only two aquaculture feed lines are commercially manufactured in Kenya. The tilapia pellet is manufactured as a dry 3 mm pellet using a commercial steam pelletizer (capacity 4 tonnes/hour) and an indoor pellet drier. Approximately 58.8 tonnes of tilapia pellets were produced by Atta Kenya Ltd. during 2005 (4.9 tonnes/month), with an ex-factory price of Ksh 17/kg). The trout starter crumble and grower pellet is manufactured by Tamfeeds Ltd. for use on its own trout farms and for sale to other trout farmers in Kenya. The feed is produced as a moist pellet using a simple motorized meat extruder and dried outdoors; the pellet is composed of local ingredients (see Table 14). Approximately 45 tonnes of dry trout feed was produced by Tamfeeds Ltd. during 2005 (at an ex-factory price of Ksh 41/kg. In 2005, a total of 104 tonnes of aquafeeds were produced by the formal feed sector. Given that catfish farming is growing rapidly there is a need for the industry to develop a feed for this species.

Currently, there are no quality standards and the industry is largely unregulated. However, this problem is now receiving the necessary attention. Feeds are basically formulated on biological and economic considerations only.

4. CONSTRAINTS TO SUSTAINABLE AQUACULTURE DEVELOPMENT

Regional availability and accessibility of feed ingredients

Fishmeal is more readily available in the Lake Victoria region than in other areas, whereas wheat bran is more readily available in some parts of the Rift Valley and Central Province, than in other regions. Farm-made feeds are also not readily available and industrially manufactured tilapia and trout feeds are only available in Nakuru and Nairobi. High transportation costs put many feed ingredients and feeds beyond the means of the majority of fish farmers in Kenya. Commercially manufactured diets and high protein ingredients such as

Omena and oilseed cake are too expensive for small-scale farmers. At present many potential feed resources still remain unexplored in Kenya. These include abattoir wastes (meat, bones, blood, hair, feathers, gastro-intestinal tracts, rumen contents), sugar cane factory wastes (bagasse), coffee processing wastes (coffee pulp), and occasionally corn mill sweepings.

Storage

Facilities for the storage of feeds or ingredients are generally inadequate on smallholder farms, either due to lack of knowledge or resources, resulting in a high degree of spoilage.

Feeding

Feed application rates are highly variable. There is also lack of consistency in feeding. Feeding rates are not adjusted regularly as required.

Demand

The current estimated annual production of just over 1 000 tonnes of fish probably explains the undeveloped state of the aquafeed industry. Assuming a feed conversion ratio of 2.5:1, only 2 500 tonnes of feed would be required per annum. This is approximately 0.5 percent of current national animal feed production and is too little to justify any significant investment. Opportunities to develop the aquafeed industry are technically determined by the rate of development of aquaculture itself.

Farm-made feeds tend to be of variable quality, depending on availability of by-products on the market or from the farm. Overall, feed remains one of the biggest obstacles for the expansion of aquaculture in Kenya, especially in medium- and large-scale production systems. Unless affordable feeds can be provided, farm-raised fish products cannot compete with those from marine and inland capture fisheries. In conclusion, there are significant challenges with respect to the availability of feed ingredients and feeds, accessibility, quality, and quantity that impede the development of the sector.

5. RECOMMENDATIONS FOR IMPROVED UTILIZATION OF FERTILIZER AND FEED RESOURCES

- The government must provide an enabling legislative environment for the sustainable and responsible development of the aquaculture sector.
- There is an urgent need for increased collaboration within and between the private and public sectors engaged in aquaculture development activities, including research that addresses aquaculture feed technology and applied nutrition.
- The Livestock Feeds Bill needs to be finalized by the Department of Livestock Production to facilitate the development of high quality aquafeeds.
- The dissemination of information to enhance supplementary feeding methods and appropriate feed storage must be improved.
- Training of technicians in feed technology and nutrient application.
- Farmers with limited cash resources should be trained and encouraged to use low-cost agricultural by-products such as abattoir wastes, mill sweepings and rice bran.
- Surveys of available feed resources should be undertaken on a district basis. This information can be used to assist farmers to develop their own feeding strategies that will lead to improved fish production and optimal use of agricultural by-products within the region.

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Analysis of feeds and fertilizers for sustainable aquaculture development in Malawi

S.K. Chimatiro and B.B. Chirwa
Department of Fisheries
PO Box 593, Lilongwe
Malawi

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SUMMARY

Aquaculture was introduced to Malawi in 1950 as a means to provide protein for human consumption. Despite several attempts to initiate commercial aquaculture between the mid 1970s and the late 1990s the sector continues to be mainly a small-scale activity. However, since 2003 significant investments have been made by the private sector to produce fish on a commercial scale. A cage culture operation has been set up in Lake Malawi to produce 3 000 tonnes of indigenous tilapia (chambo *Oreochromis karongae* and *O. shiranus shiranus*) and a 120 tonne per annum semi-intensive pond based farm (Mozambique tilapia *O. mossambicus,* common carp *Cyprinus carpio* and North African catfish *Clarias gariepinus*) has been successfully initiated in the Lower Shire valley.

Small-scale, integrated pond culture prevails and at this stage accounts for 90 percent of the total aquaculture production. There are approximately 4 000 small-scale fish farmers, several of whom have become commercially orientated in recent years. There is uncertainty with regard to total fish production and estimates range from 50 to 800 tonnes. Small-scale pond yields vary from 0.5–2.3 tonnes/ha/year, while commercial farmers realise approximately 10–12 tonnes/ha/year. The most common species in small-holder aquaculture is *O. shiranus shiranus,* though many small-scale farmers now prefer to grow redbreast tilapia (*T. rendalli*). The average pond size is around 200 m^2 and stocking densities are low (2–3 fingerlings/m^2). The most commonly used feed is maize bran. The overwhelming majority of small-holder farmers in Malawi are resource limited and chemical fertilizers are not commonly used for pond fertilization and as such, most use vegetable compost cribs in their ponds. The use of animal manure (chicken, pig, goat and cattle) is restricted due to inadequate purchasing power, high transportation cost and inadequate storage facilities. Hence, farmers do not have access to sufficient quantities for optimum pond fertilization and production.

While suitable agricultural products and by-products such as maize bran, oilseed cakes, carcass meal are available all year round, competition from the poultry feed industry is intense and most farmers are unable to purchase and use them. On-farm agricultural by-products such as maize bran, green vegetables, high protein leaves, fruit and kitchen waste are the principal feeds used in small-holder aquaculture. The seasonal availability of farm by-products is dictated by the agricultural calendar.

The poultry feed industry is reasonably well developed, annually producing in excess of 100 000 tonnes. Fishmeal, soybean and oilseed cake production does not meet the industry's demand and are mainly imported; hence fish feeds are not made on a commercial basis, although one company supplies formulated concentrates and a small quantity of pellets. Presently, the two commercial farms and some of the small-scale commercial farmers formulate, compound and manufacture their own farm-made feeds. Feed formulations vary widely from complete diets to mixtures of chicken growers mash mixed with cooked soybean meal. Farm-made feeds range from stiff cooked porridge, moist dough, moistened formulated mixtures to farm-made pellets. Feeding practices also vary widely. Non-commercial farmers feed their fish at irregular intervals, depending on the availability of resources and by-products. Commercial farmers, irrespective of scale, feed their fish according to scheduled programmes depending on pond or cage biomass. Feeding practices also vary by region or district depending on the level of extension and farmer knowledge.

Problems and constraints facing the animal feed industry include the high cost of transport, the performance of the agriculture sector, the capacity to store adequate quantities of ingredients by small-holder farmers and lack of farmer knowledge regarding the value of feeding fish.

Malawi has recently developed and adopted a National Strategic Aquaculture Plan. For the aquaculture sector to grow requires the aggressive implementation of the strategic plan.

1. GENERAL OVERVIEW OF AQUACULTURE AND FARMING SYSTEMS

Rural, small-scale fish farming in Malawi commenced in the late 1950s. From the early 1970s through to the mid-1990s, donor and NGO support played a major role in the development of the sector in Malawi. Consequently, small-scale fish farming is now widely practised throughout many parts of the country (Figure 1). Commercial fish farming began in 1906 with the introduction of rainbow trout (*Onchorhynchus mykiss*) for angling purposes (Balarin, 1987). After a series of false starts and failures the commercial sector now finally seems to be on the right track.

Pond culture is the prevailing aquaculture practice in Malawi. Cage culture has only recently been introduced. The number of fish farmers has increased from less than 100 in the 1960s to 2 000 in 1997 (Dickson, Brooks and Sikawa,1997) and currently there are approximately 4 000 farmers (SSC, 2003; ADiM, 2005b). Most farmers have integrated fish farming with horticulture and/or animal husbandry. The four major species cultured in Malawi, are chambo (*Oreochromis karongae*) and makumba (*O. shiranus shiranus*), redbreast tilapia (*Tilapia rendalli*) and North African catfish (*Clarias gariepinus*). However, *O. shiranus shiranus* and *Tilapia rendalli* are the most popular species, accounting for over 90 percent of total fish production (Table 1).

TABLE 1
The species and their contribution to aquaculture production

Fish species	Contribution %
Tilapia	93
Catfish	5
Exotic fishes*	2

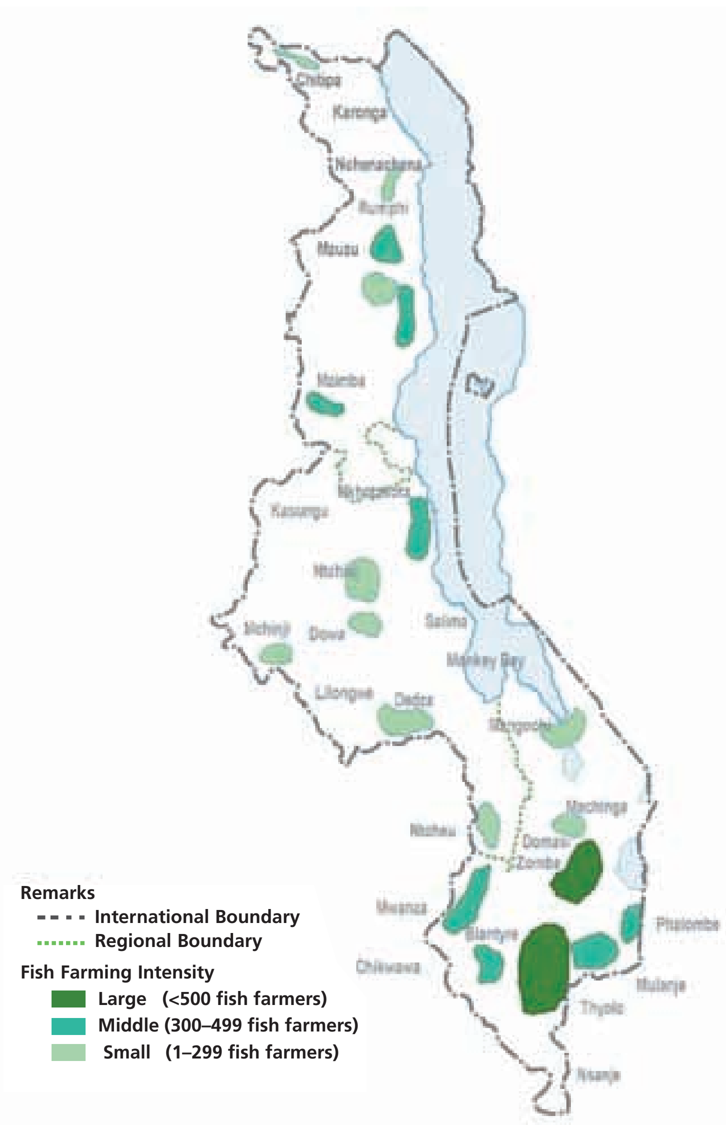
*Exotic species are mainly common carp and a smaller quantity of rainbow trout

Source: NAC (2002)

O. shiranus shiranus is endemic to Lake Malawi and the Upper Shire River and is widely distributed amongst the natural water bodies and in fishponds in all parts of the country. It is the most common fish in Malawian fish ponds. Due to its early maturity, precocious breeding traits and the poor farming conditions the species does not reach its growth and or production potential. The average weight of the fish in farmer ponds is 19.3 g (Range 6–140 g) (n=2 398) (ADiM, 2005b).

Tilapia rendalli is becoming the most favoured aquaculture species in the country. This is because of its superior growth rate over *O. shiranus shiranus*, under the prevailing farming conditions, consumer demand and price.

FIGURE 1
Fish farming activities in Malawi



Source: ADiM (2005b)

TABLE 2
Estimated aquaculture production in Malawi

Year	Production (tonnes)
1995	200
1996	210
1997	250
1998	340
1999	550
2000	640
2001	750
2002	800

Source: NAC (2002)

Common carp (*Cyprinus carpio)* was introduced into Malawi in 1976, and is restricted to the Lower Shire catchment. The importation and distribution of carp was prohibited in 1992 and this is enforced under the Fisheries Conservation and Management Act (1997). Rainbow trout continues to be farmed on the Zomba Plateau and some remnant populations occur on Mount Mulanje and some dams and rivers on the Nyika Plateau.

The average fish farmer in Malawi has one or two fishponds with a mean size of approximately 200 m^2 depending on land availability (Figure 2), although some of the more progressive farmers have up to 18 ponds. Fishponds are usually stocked with fingerlings left over from the harvest or from other ponds on the farm. More often than not, this means that mature stunted fish with little scope for growth are mistakenly stocked as fingerlings. Ponds are stocked at 2 to 5 fish per m^2 depending on supply, availability, price and transport (Brummett and Noble, 1995; ADiM, 2005b). Fishponds are fertilized using plant material in compost cribs or with poultry, goat and/or cattle manure and fish are fed with on-farm agricultural by-products, such as maize or rice bran, if available.

Integrating aquaculture with agricultural is now a common practice amongst over 2 500 farmers. A medium-scale pond farm (GK Aquafarms in the Lower Shire) and a large-scale cage culture operation (MALDECO Aquaculture in Mangochi) were established in 2004. MALDECO Aquaculture aims to produce 3 000 tonnes of chambo (*Oreochromis karongae* and/or *O. shiranus*) per annum and GK Aquafarms produces around 120 tonnes of *O. mossambicus* and common carp per annum.

There is some uncertainty with respect to total aquaculture production in Malawi. In 2002, the NAC estimated total production to be 800 tonnes (Table 2), while the ADiM project (ADiM, 2005a) estimated total production in 2003 to be between 50 and 200 tonnes. The apparent over-estimation by NAC (2002) is attributed to the small sample size of farmers used for the estimation of mean yield and total production. Yields vary from 500–2316 kg/ha/year depending on the level of intensification, with an average yield of 1.4 tonnes/ha/year (ADiM, 2005a). This translates into an annual income of US$1 363 ha/year (approximately US$25 farmer/year).

2. REVIEW AND ANALYSIS OF FERTILIZERS, FEEDS AND FEEDING

All small-holder agricultural enterprises in Malawi are resource limited (ICLARM & GTZ 1991, ADiM, 2005a). As elsewhere, feeds and fertilizers are the most important inputs in commercial and non-commercial aquaculture. ARTDMIS (2005) demonstrated that production could be increased to 2000 kg/ha by optimising fertilization practices. However, higher production from small-holder fishponds is limited by the affordability, availability and access to quality inputs (feed, manure and fertilizer). During the early 1990s, Brummett and Noble (1995) estimated that only 27 percent of the pond nitrogen requirements were met in integrated aquaculture systems. There is no evidence to suggest that the situation has changed since then.

2.1 Availability of fertilizers, feed ingredients and feeds

2.1.1 Chemical fertilizers

Fertilizer and feed availability are two major determinants of successful fish farming operations in Malawi (Masuda, Chirwa and Ntenjera, 2004). In fishponds, nitrogen and phosphorus are the most limiting nutrients; hence fish farmers in Malawi are encouraged to apply either inorganic or organic fertilizers depending on availability. The commonly available inorganic fertilizers are single, double or triple super phosphate, four NPK compounded fertilizers (A, B, C and D), di-ammonium phosphate (DAP),

TABLE 3
Chemical composition of various fertilizers

Type of fertilizer	Chemical composition				
	Nitrogen	Phosphorus	Potassium	Sulfur	Boron
NPK compound A	2	18	15	4	0.1
NPK compound B	4	18	15	4	0.1
NPK compound C	6	18	15	4	0.1
NPK compound D	8	18	15	4	0.1

Source: Ministry of Agriculture (2003)

mono-ammonium phosphate (MAP) and 23:21:0+ 4S. The chemical compositions of the NPK fertilizers are shown in Table 3.

All chemical fertilizers used in Malawi are imported. The annual increase in fertilizer prices, over the past eight years is indicated in Table 4.

TABLE 4
Quantities of fertilizers and cost, imported by Malawi during 1998-2005

Year	Quantity (thousand tonnes)	Unit cost (US$/tonne)
1998	79.9	253.5
1999	165.0	163.2
2000	58.2	215.5
2001	18.2	244.5
2002	143.2	296.9
2003	169.5	247.6
2004	173.8	368.7
2005*	200	465.6

*Projected by the authors from fertilizer imports
Source: ADiM (2005a)

However, inorganic fertilizers are rarely used in fish farming because of the high unit price. Generally, small-holder farmers use chemical fertilizer at an average application rate of 70 kg/ha for crop farming, but do not apply any to their fishponds (Chimatiro, 1992; ADiM, 2005a). The majority use animal manure to fertilize their fishponds at variable application rates, depending on availability.

2.1.2 Organic fertilizers

Animal manure (chicken, goat, sheep and cattle) and compost are the most commonly used organic fertilizers in Malawian aquaculture. The nutritive values of chicken and goat manure are presented in Table 5, though composition varies depending on source, processing and the manner in which it was stored. More recently, farmers have been encouraged to keep ducks around their fishponds and to keep their goats in pens, such that manure can be collected and applied to the ponds (Figure 2).

The availability of manure was estimated from on-farm livestock populations. On a national basis, the livestock of each small-holder household generates approximately 7 kg of wet manure on a daily basis (2.6 tonnes/year) or 4.39 kg/day (1.62 tonnes/year) of solid manure. Table 6 summarizes the average quantity of available manure.

FIGURE 2
Ducks kept within the enclosure of the fishpond for deposition of manure in the pond (left) and fish farmers collecting goat manure from a goat house to be applied to fishponds (right)

TABLE 5
Nutrient values (dry matter basis) of some farm manures in Malawi

Manure type	Nitrogen (g/kg)	Phosphorus (g/kg)	Dry matter proportion	Organic matter proportion
Goat manure	40.8	4.47	0.50	0.32
Chicken manure	3.0	4.82	0.74	0.27

Source: Brummett (1998)

TABLE 6
Average available manure per household

Livestock species	Total number*	Number per household	Live weight per animal (kg)**	Wet manure/ household/day (kg)**	Solid waste/ household/day (kg)**
Cattle	764 061	0.33	210	4.21	2.91
Goats	1 922 264	0.82	30	1.71	0.81
Sheep	226 913	0.10	30	0.20	0.10
Pigs	477 863	0.21	58	0.71	0.38
Chickens	9 947 612	4.22	1.25	0.37	0.19
Total				**7.20**	**4.39**

Source: *Malawi Government (2005); **calculated from Aguilar-Manjarrez and Nath (1998) and Coche, Muir and Laughlin (1996)

Approximately 85.6 percent of fish farmers in Malawi are reported to regularly apply animal manure to their fishponds, although the quantities applied are too low to satisfy the nutrient requirements (ADiM, 2005a). In most cases it is difficult to collect the manure produced because most the animals are kept under free-range conditions. Alternatively, chicken manure could be purchased from commercial poultry farms. However, high transport costs (US$1.00 per km for loads of up to 1 tonne), makes it difficult for rural fish farmers to access this resource. In a survey in the Southern region, Masuda, Chirwa and Ntenjera (2004) found that only 2 percent of farmers regularly purchased animal manure. Most fish farmers use compost made by regularly or irregularly adding grass and plant material in compost cribs in their ponds (Figure 3).

FIGURE 3
Composting crib using maize stalks

2.1.3 Supplemental feeds

Maize bran is the most commonly available cereal by-product and is used by over 84 percent of fish farmers (Masuda, Chirwa and Ntenjera, 2004). Its nutritive value varies depending on the milling process and contains 7–10 percent crude protein (Table 7).

Chimatiro (1992) and Kapalamula (1993) developed comprehensive farming calendars for fish farms in Malawi (Table 8). Most fish farmers in Malawi commence their activities by preparing the garden during May by tilling the soil and planting occurs soon after the first rains in November or December.

Where farmers integrate fish farming with agriculture a range of vegetables and fruits are grown in beds adjacent to the ponds or on the pond dykes. These gardens, locally known as *dimba* gardens, produce relatively more food per hectare than other areas on the farm, because pond seepage keeps the soil moist all year round (Chimatiro, 1992).

TABLE 7

Proximate nutritional composition of the major fish feed ingredients (percent dry matter basis)

Material	Dry matter	Crude protein	Crude lipid	Crude fibre	Ash	NFE*	Source
Maize bran germ	86.9	7.4	3.4	6.5	1.0	81.7	1
Maize bran husk	87.7	7.1	4.1	15.3	1.9	71.6	1
Maize bran	92.0	10.1	9.6	14.7	11.0	54.5	2
Wheat bran	87.7	13.8	10.8	9.1	1.1	52.9	1
Fishmeal	87.0	47.3	21.9	0.8	26.9	0.1	3
Meat & bone meal	98.7	55.6	25.3	0.1	14.7	-	5
Cotton seed oil cake	-	19.5	10.4	8.2	3.7	-	5
Sunflower oil seed cake	98.5	25.3	15.3	22.9	5.3	-	5
Soybean	94.2	52.9	1.4	4.0	6.7	-	5
Rice bran	91.0	14.0	-	-	-	-	4

NFE = Nitrogen free extract; - = data not available

Source: (1) Metcalfe (1977), (2) Ohashi *et al.* (1999), (3) Masuda *et al.* (2004), (4) Mtimuni (1995), (5) Nyirenda *et al.* (2000)

TABLE 8

Agricultural calendar for typical small-holder farming systems in Malawi

Month	Main farming activities	Agricultural by-product availability
Oct	Preparing maize fields, harvesting vegetables gardens, tending to tobacco nurseries.	Limited supply of organic fertilizers (compost) to fish ponds as most of it is applied to maize fields. Vegetable wastes available to feed *Tilapia rendalli.*
Nov	Planting maize & tobacco, weeding, and fertilising maize crop.	Weeds available in limited supply as labour is committed to maize and tobacco growing and distances between maize fields and fishponds. Limited supply of in organic fertilizer to fish ponds as most of it is applied to maize fields.
Dec & Jan	Transplanting rice field. Planting yams, cassava, and sweet potatoes in maize fields. Weeding.	Weeds available but limited in supply, as labour is committed to rice transplanting and growing of other crops.- Crop leaf matter from cassava, sweet potatoes are available.
Feb	Harvesting tobacco & beans Weeding in maize field. Planting yams, cassava, and sweet potatoes in maize field.	Weeds available but limited in supply, as labour is committed to rice transplanting and growing of other crops. Crop leaf matter from cassava, sweet potatoes are available.
Mar	Harvesting maize, beans, chillies & tobacco, selling sugarcane, Fertilising & weeding rice, sweet potatoes, cassava and vegetable garden preparation.	Maize bran and vegetable leaf from cassava, sweet potatoes available. Selling of other crops e.g. sugarcane provides cash to buy maize bran.
Apr	Harvesting maize, groundnuts, rice, and tobacco. Growing vegetables in nurseries.	Maize bran and Vegetable leaf from cassava, sweet potatoes available. Selling of other crops e.g. sugarcane, assists to provide cash to buy maize bran.
May & June	Harvesting maize, ground nuts, sugarcane, rice, yams, cassava, sweet potatoes, sorghum and tobacco. Selling sugarcane, maize, and groundnuts and growing vegetables.	Peels and leaves of cassava and yams are available, maize bran, rice bran and pulses are plenty during this time and vegetable wastes available
July	Growing vegetables. Harvesting cassava, sweet potatoes, sugarcane and vegetable. Selling maize, rice sorghum, groundnuts & tobacco.	Maize bran, rice bran and pulses are plenty during this time. Peels and leaves of cassava and yams are available.
Aug & Sept	Growing vegetables, harvesting, selling rice, sweet potatoes & cassava and prepare maize fields.	Vegetable wastes available, Rice bran available, Maize bran scarce.

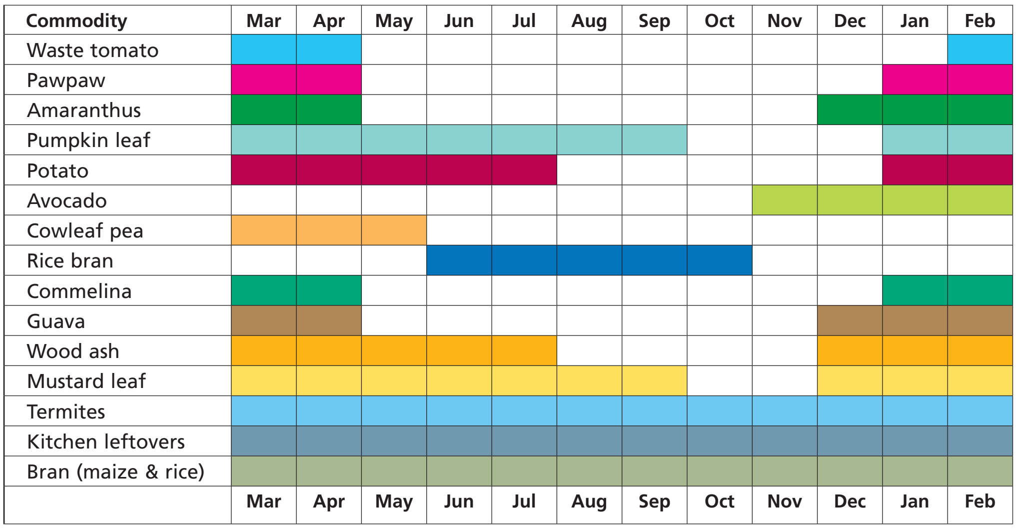
Source: Adapted from Chimatiro (1992) and Kapalamula (1993)

Harvesting of most crops starts in April or May (Table 8). A range of on-farm pond inputs are available, such as over ripe fruit (bananas, paw paws, mangos), kitchen left-over, maize and rice bran, potato, cassava and coco yam leaves or peelings, vegetable leaves (cabbage, pumpkin), maize and rice bran as well as wild vegetation and termites.

Availability of on-farm agricultural by-products is seasonal (Figure 4). More by-products are available during and just after the rainy season than during the dry season, with an input-gap at the beginning of the rainy season when most of the arable lands on the

FIGURE 4

Seasonal availability of pond inputs on small-holder fish farms in Zomba District, south Malawi



Source: Chimatiro (1992)

TABLE 9

Household and agricultural by-products produced on an average Malawian small-holder farm of 1.57 ha

Material	Quantity (kg)	Approximate dry matter (kg)
Firewood ash	438	438
Maize bran	296	192
Rice bran	54	35
Rice straw	888	275
Maize stover	2 513	2 262
Weeds	1 595	494
Total	**5 784**	**3 696**

Source: Noble and Chimatiro (1991)

farms are dry (Chimatiro, 1992). Maize bran is obtained from on-farm maize production or is purchased. The majority of rural fish farmers do not produce adequate amounts of maize bran to feed their fish at recommended levels through out the production cycle. Maize bran is readily available from March to early August (Table 8). However, during the times of food shortage (usually between August and February), there is competition for maize bran since the bran is then also used for human consumption.

Due to the increasing demand for maize bran as an ingredient in livestock feed, small-scale farmers find it difficult to obtain adequate quantities during certain times of the year. During such times alternative brans (rice and wheat) are used, though these commodities are now also in greater demand by the local animal feed industry.

Fishmeal and other agro-industrial by-products such as sunflower, cotton and groundnut oilseed cake and abattoir by-products such as meat and bone meal are rarely used on small-holder fish farms. Realising the value good feeds some small-holder fish farmers have recently started growing soybeans as a feed ingredient. Except for GK Aquafarms, little use is made of pulses such as pigeon peas, cowpeas and chickpeas as feed ingredients. The available on-farm resources and their nutritive values are summarised in Tables 9 and 10.

2.2 Feed management strategies

Most fish farmers source their feed ingredients (mainly bran) during the harvest season when prices are lower. Fertilizers are difficult to obtain and if sourced, priority is given to crop production. Most fish farmers do not produce enough manure and the more progressive farmers purchase the required quantities. Because of it bulky nature, manure is difficult to store. Most farmers therefore purchase manure when required and apply it immediately (Masuda, Chirwa and Ntenjera, 2004).

TABLE 10
Proximate composition of some household and on-farm resources in Malawi

Material	Nitrogen g/kg (DM)	Phosphorus g/kg (DM)	Dry matter	Organic matter
Nsima (maize porridge) left overs	91.0	-	0.23	0.05
Watermelon	33.9	3.0	0.06	0.10
Pumpkin, fruit	23.2	2.6	0.11	0.09
Pumpkin, leaves	41.4	2.8	0.14	-
Pumpkin, flowers	54.0	-	0.03	0.54
Termites	600.0	-	0.50	-
Napier grass	24.3	1.7	0.31	0.25
Crotalaria	30.3	2.8	0.24	0.22
Guava	15.0	-	0.12	-
Coco-yam leaves	31.4	1.1	0.15	0.12
Pea/bean pods	24.1	0.9	0.90	0.86
Pigeon pea leaves	30.2	2.4	0.35	0.32
Sweet potato leaves	-	2.8	0.11	0.09
Coatbuttons (*Tridax procumbens*)	119.0	-	0.14	-
Cassava leaves	40.5	6.0	0.16	0.15
Turnip tops	43.3	3.6	0.20	0.14
Mixed grass	13.5	1.9	0.48	0.38
Mango fruit	350.0	1.0	0.17	0.17
Leucaena leaf	41.1	1.5	0.31	0.27
Maize stovers	7.0	5.1	0.90	0.72

DM = dry matter

Source: Adapted from Brummett (1998)

The amounts of manure and feed applied by the majority of fish farmers, or other technologies such as periphyton enhancement techniques (Jamu, Chaula and Hunga, 2003; Chirwa, 2003) are not adequate to achieve and sustain optimum primary productivity and fish growth. Farmers are also encouraged to adopt technologies such as deepening their ponds to improve production and to reduce the rate of seepage to retain nutrients (ARTDMIS, 2005).

TABLE 11
Compounded feeds for *Clarias gariepinus*

Ingredient	Fry (%)	Fingerlings & brood stock (%)	Grow out (%)
Usipa fishmeal*	50.0	30.0	20.0
Meat & bone meal	12.5	15.0	15.0
Bloodmeal	0.0	5.0	5.0
Soybean meal (full fat)		15.0	22.0
Maize bran		11.5	13.5
Milk powder	10.0		
Wheat flour	25.0	22.0	22.0
Vitamin mix	2.0	1.0	2.0
Mineral mix	0.5	0.5	0.5

*Lake sardine (*Engraulicypris sardella*)

Source: Ohashi *et al.* (1999); Ohashi *et al.* (2001)

2.3 Feed formulations

Malawi does not have a formal aquafeed industry and given the size of the commercial aquaculture sector the hesitancy by the animal feed industry to invest in this sector is understandable. The Department of Fisheries, through the National Aquaculture Centre (NAC) has therefore developed several feed formulations for catfish (Table 11), tilapia and carp (Table 12).

TABLE 12
Compounded feeds for broodstock and fingerlings of catfish, carp and tilapias

Ingredient	%	Crude protein	Crude lipid	Ash	Crude fibre	NFE
Fishmeal	30.0	13.1	12.4	2.5	14.9	0.7
Meat and bone meal	15.0	3.1	2.6	1.3	5.1	0.1
Blood meal	5.0	0.6	0.0	0.0	0.1	0.02
Soya meal	15.0	2.2	4.5	5.6	0.9	1.8
Wheat flour	22.0	2.0	1.4	1.8	0.6	11.3
Maize bran	10.5	0.1	0.6	3.9	0.2	3.3
Vitamin mix	2.0	0.0	0.0	0.0	0.04	0.02
Mineral mix	0.5	0.0	0.0	0.0	0.01	0.00
Total	100.0	37.0	9.4	2.4	13.9	28.2

Source: NAC (2001)

2.3.1 Feed preparation, cost and storage

The largest commercial aquaculture project in Malawi purchases milled raw materials from a livestock feed manufacturing company. If necessary, the dry ingredients are milled to a smaller particle size, mixed with a binder and pelleted on the farm. The company is presently experimenting with various formulations. Various size pellets are made according to requirements.

GK Aquafarms sources ingredients from various quarters (farmers, importers and animal feed manufacturers), which are then milled, compounded and cooked and fed to the fish as moist feed balls or in perforated bags, suspended in the water column. Both of the two large-scale operations have adequate feed storage facilities.

A small number of innovative farmers have realised the value of formulated feeds and have been experimenting with feed formulation. They similarly purchase feed ingredients such as soybeans (which are cooked or roasted), maize, dried fish (pounded to fishmeal), as well as maize and rice bran and manufacture their own pellets using home made pellet machines, such as plungers or meat mincers. Alternatively they purchase chicken mash and mix this with cooked soybean flour to make their pellets.

There is one feed company in Malawi that manufactures a tilapia pellet. However, the feed is sub-optimal in terms of its formulation, physical properties and price (ADiM, 2005b). MALDECO has taken the challenge to undertake joint research with the Department of Fisheries, University of Malawi's Bunda College and the WorldFish Centre, to develop a feed formulation using locally available ingredients and a minimum quantity of fishmeal.

The average labour cost to produce one tonne of farm-made feed has been estimated at about US$7.34 (Masuda *et al.,* 2004), which is equivalent to around a weeks wage for a farm worker.

2.3.2 Feeding methods, feeding frequency

Chimatiro (1992) and Masuda, Chirwa and Ntenjera (2004) reported that cereal bran (maize and rice) (Figure 5) and manure are simply broadcast over the water surface, while waste fruits and vegetables as well as grass and maize stovers are placed into the pond cribs. The quantities applied depend on the availability of the materials and not on fish biomass. This makes it very difficult to establish exactly how much is applied. However, in a survey of a number of fish farmers in Zomba District, Chimatiro (1992) established that farmers applied bran and kitchen waste at a daily average of 1.05 and 0.07 kg/200 m^2 and 0.2 kg of manure/200 m^2 /day (Table 13).

FIGURE 5
A fish farmer in Zomba West applying maize bran to her fishpond – a very wasteful method of applying feed, emphasising the need for improved extension services

TABLE 13
Average quantities of inputs applied to fishponds in Zomba District, Malawi

Resource	Application rate (g/200 m^2/day)
Cereal (maize & rice) bran	1 058.6
Termites	122.6
Waste vegetables	421.4
Waste fruits	60.7
Livestock manure	201.2
Kitchen left-over	67.9
Napier grass	183.0
Compost	7.1
Mushrooms	3.6

Source: Adapted from Chimatiro (1992)

TABLE 14
Feeding frequencies in southern Malawi

Feeding frequency per day	Percent of farmers
Less than once a day	5
Once a day	35
Twice a day	40
More often	8
Not known	12

Source: Adapted from Masuda, Chirwa and Ntenjera (2004)

Feeding frequency varies widely amongst fish farmers. The majority of farmers feed their fish whenever feed is available and when they have the time. Masuda, Chirwa and Ntenjera (2004) reported that 5 percent of farmers in southern Malawi feed their fish less than once per day, while 40 percent of farmers feed their fish twice a day.

All commercial fish farmers (small and large-scale) either apply the feed in the form of a moist mash in feeding bags or on trays or in pellet form. The fish are fed on a regular basis (the daily frequency depends on average fish size) and a ration based on pond or cage biomass (which is adjusted every second week).

TABLE 15
Animal feed production by some feed manufacturing companies

Feed Production Unit	Total annual production (tonnes)
Bwemba Chicken Farm	252
Central Poultry Ltd	30 000
Proto Feeds	35 000
Foundation for Improvement of Animal Health (FIAH)	*
NALI RHO	*
Mbado Feeds	*
Grain Tech	*
Lama Feeds	*
J & M Feeds	*
National Stock Feeds	*
Trans Globe	*
International Multi Food Corporation	*

*Companies regarded production volumes as confidential

Source: Company representatives

3. THE ANIMAL FEED MANUFACTURING SECTOR

The animal feed industry is relatively well established. However, the aquafeed industry is still nascent. There are several big and small-scale companies that produce concentrates for on-farm mixing as well as complete feeds (Safalaoh, 2002). The companies include Rab Processors, Bwemba Chicken Farm, Foundation for Improvement of Animal Health (FIAH) feed mill, Proto feeds, NALI RHO, Mbado Feeds, Grain Tech, Lama Feeds, J & M Feeds, National Stock feeds, Trans Globe, Central Poultry Ltd. and International Multifood Corporation. Table 15 below provides production figures of some of these companies. It was not possible to establish the total volume of compounded feeds produced in Malawi as many of the producers were reluctant to reveal this information. However, it would be safe to say that the total probably exceeds 100 000 tonnes.

Most of these companies operate in the urban areas of Blantyre (southern region), Lilongwe (central region) and Mzuzu (northern region) and mainly manufacture poultry feeds. There are no feed manufacturing associations in Malawi and as a result these companies operate as separate entities. The Government of Malawi recently enhanced the development of the poultry feed industry by establishing the Poultry Development Programme. The programme enables small-holder and medium size chicken farmers to access funding in order to improve production. This will lead to a higher demand for quality poultry feeds and an increase in the number of feed producers.

The Malawi Bureau of Standards (MBS) regulates feed manufacturing. The mandate of the MBS is to prescribe and enforce product standardisation in Malawi. It also regulates feed manufacturing indirectly through various requirements on feed ingredient imports and exports. The Chemicals and Drugs Board of Malawi regulates the imports of vitamins and minerals as well as all drugs, which are added to the manufactured feeds. All stock feed ingredients that are imported must meet sanitary requirements. The importation of feed ingredients that might contain genetically modified organisms (GMOs) is regulated by the National Bio-Safety Act.

TABLE 16
Major feed ingredient imports in 2002

Feed ingredient	Quantity (tonnes)
Soybean	4 786
Wheat bran	556
Maize bran	648
Other cereal brans	5

Source: National Statistical Office, unpublished data

TABLE 17
Average cost of animal feed additives, 2005

Ingredient	Cost (US$/kg)
Premixes	5.94
Methionine	7.58
Lysine	6.97
Eskaline	6.56
Flavamycine	5.33
Mono calcium phosphate	1.23
Common salt	0.62

Source: Golden Chicks and Bwemba hatcheries (pers. comm.)

Feed and ingredient imports and export

Current data on animal feed imports and exports are not readily available. At this stage it would appear that Malawi does not export livestock feed or feed ingredients. Table 16 summarizes major feed ingredient imports, although these figures are considered be inaccurate.

Malawi is a member of the World Trade Organisation (WTO), the Common Market for Eastern and Southern Africa (COMESA) Free Trade Area. Therefore, the country operates under a framework of liberalised trade. Malawi also has bilateral and preferential trade agreements with other countries, such as South Africa, Zimbabwe and Botswana. Imported feeds normally attract certain tariffs, depending on the country of origin. A surtax of approximately 17 percent is levied on most of the feeds produced and purchased locally. The government issues import and export licences for all compounded products for animal feed.

Additives such as vitamins, minerals, antibiotics and binders are readily available in Malawi. These can be purchased from pharmacies and feed manufacturers. It is common for farmers to purchase the vitamins and minerals as premixes. Table 17 indicates the cost of some of the animal feed additives.

3.1 Problems and constraints

In general, the animal feed industry in Malawi is constrained by the lack of locally produced commodities. This in turn is caused by the variable performance of the agricultural sector in Malawi. For example, the growth in the agricultural sector ranged from -6.7 percent to +6.2 percent per annum between 2000 and 2005 (Malawi Government, 2005). Consequently, the bulk of the ingredients for livestock and fish feeds have to be imported to ensure a consistent supply. Malawi is a landlocked country where transport costs tend to account for nearly to 30 percent of the overall cost of imported goods. Most of the suppliers and feed manufacturing companies are situated in the major urban centres of, whilst most farmers are in rural areas. The added cost of transport and handling places feeds out of reach for most farmers.

While significant progress has been made by the two large-scale commercial farms to manufacture their own farm-made feeds, small-holder fish farmers have lagged behind. One of the contributing factors has been the lack of basic equipment, such as milling, mixing and pelleting machinery. Several small-holder farmers have however developed innovative techniques for making on-farm feeds, although the majority are still not conversant with these basic methods. These techniques are not very different to those used by small-scale farmers in Asia. The fact that Malawian small-scale farmers have only now been sensitised to these methods suggests that extension services must to be improved.

The requirement for storage of feed ingredients and farm-made aquafeeds is based on the assumption that farmers are able to accrue and/or purchase their feed ingredients when prices are low. However, the high transport costs and the capital required to build adequate storage facilities prevents most farmers from following such a plan and hence they purchase just enough for their immediate need. Purchasing and handling feeds in bulk by farmer groups or clubs would enable them to operate on economies of scale, leading to reduced transportation and handling cost and better profits.

The major problem that has been identified is that small-scale farmers do not feed their fish and fertilize their ponds as regularly as recommended (Noble and Chimatiro, 1991; Brummett and Noble, 1995; Masuda *et al.*, 2004, ADiM, 2005b). This is mainly because most farmers cannot afford the necessary feeds and nutrients and lack basic knowledge.

4. RESOURCE AVAILABILITY AND EXPANSION OF THE AQUACULTURE INDUSTRY

Future aquaculture projections can be made on the basis of several scenarios. ADiM (2005b) made projections for small-holder aquaculture in Malawi based on a growth rate of around 15 percent per year, which could be sustained by the existing infrastructural and institutional support. Assuming two conservative production levels (15 and 60 kg/200 m² pond/year) and a current baseline of around 200 tonnes, production from small-holder fish farms will reach 1 000–5 000 tonnes per annum over a 22-year period. Given that around 25 percent of small-scale farmers are already producing at these levels the projected production level is therefore likely to be achieved.

Similar calculations and observations were made by ARTDMIS (2005), who reported that production could be increased to 200 g/m² (42 kg/200 m²/year) simply by the appropriate application of fertilizers. Similar production levels (20 kg/200m²/year) have also been reported among farmers who used organic fertilizer (manure or compost) and supplemented this with an 18 percent protein-based feed (COMPASS II, 2006). However, this can only happen if farmers can afford the required volumes of manure and the constraint of access to fertilizers can be resolved. Current Government initiatives, including the Presidential Initiative on Aquaculture Development (PIAD) which was launched in February 2006, will hopefully enable farmers to have easier and cheaper access to fertilizers in future.

In the short to medium term, the small-scale commercial sector will most definitely show rapid growth and this will be driven by the increasing demand and the rapidly escalating price of fish (currently US$2.00/kg). Farmers will also soon realise that fish farming provides better opportunities than crop farming. In fact several small-holder farmers have already realised this and are gearing up to increase production.

The third scenario is based on the expansion of large-scale fish production. Depending on the success of the current initiatives it is highly likely that others will follow. It is projected that large-scale production of fish may reach between 10 000 and 15 000 tonnes per year by the year 2015 (Department of Fisheries, 2003). Assuming a conservative Feed Conversion Ratio of 2:1, then this level of production will require a minimum of 25 000 tonnes of formulated feeds per year, creating opportunities for feed commodity importers and feed manufacturers to invest in the necessary equipment and infrastructure.

5. RECOMMENDATIONS

Recommendations to improve the utilization of fertilizer and feed resources in Malawian aquaculture can be grouped into three major categories, namely, (i) technological developments; (ii) information dissemination and outreach; (iii) socio-economic and fiscal and (iv) policy and legal framework.

5.1 Technological developments

In the short term it is critical that farmers are made aware of the opportunities presented by farm-made feeds; and already some farmers are producing their own feeds (ADiM, 2005b). However, there is a need for demand driven research to develop appropriate technologies for formulating and making farm-made feeds, using local ingredients. As far as possible this research should be undertaken on the farms and this will facilitate adoption of new technologies.

5.2 Information dissemination and outreach

Several studies have provided clear evidence that the use of fertilizers and feeds by small-holder fish farmers in Malawi is sub-optimal. Therefore, there is a need to strengthen the capacity of the extension service in Malawi to more effectively disseminate available information. Currently, the aquaculture extension services of the Department of Fisheries (DoF) in Malawi face severe challenges. To improve outreach, the Department of Fisheries has undertaken to (i) focus on high potential areas, (ii) devolution of extension services to the District Assemblies as part of the Decentralisation Policy, (iii) promotion and support of farmer-to-farmer contact and dissemination of information. Furthermore, the DoF has established and has undertaken to strengthen fish farmers' associations in the country. The first of such associations, the Innovative Fish Farmers Network (IFFN) was successfully in 2003. The IFFN is a legally constituted body with the aim to improve linkages between farmers and service providers, including the government.

5.3 Policy and legal framework

The animal feed industry, in general, is constrained by poor infrastructure, high costs and tariffs on imports. There is a need for the government to make a special effort to assist the development of the industry by promoting and supporting greater participation in this industry through various incentives such as favourable fiscal and procurement policies, ease of access to low cost capital, promotion of infrastructure development, especially in utilities such as water and electricity. Favourable tariff and tax incentives must be put in place to allow animal feed manufactures easier and cheaper access to suitable feed ingredients, locally, regionally and internationally.

The importance of fish farming must be reflected in national development policies. Some of the more recent initiatives to promote the development of the sector include, a special Presidential initiative to promote aquaculture in Malawi, the initiation of the Chambo Restoration Programme, the completion and adoption (and soon to be implemented) National Aquaculture Strategic Plan and the current revision of the National Fisheries and Aquaculture Policy (2001) to develop a stand-alone National Aquaculture Policy and Act. These and other important initiatives attest to the fact that Malawi is serious in its quest to develop the sector aggressively and responsibly.

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Analysis of feeds and fertilizers for sustainable aquaculture development in Nigeria

Olajide A. Ayinla
Nigerian Institute for Oceanography and Marine Research
Victoria Island, P M B 12729, Lagos
Nigeria

Ayinla, O.A. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Nigeria. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome: FAO. pp. 453–470.

SUMMARY

The study provides a synthesis of the status and trends in the use of feeds and nutrients for sustainable aquaculture development in Nigeria. The rapid and progressive development of aquaculture in Nigeria is necessary to bridge the gap between fish demand (1.5 million tonnes annually) and supply (0.5 million tonnes annually). Following a series of false starts, aquaculture is now passing through an exciting phase of evolution and in 2004 Nigeria produced 43 950 tonnes of fish. Nigerian farmers have recognised the importance of using formulated feeds for commercial aquaculture development.

The culture system of choice is polyculture of tilapia (mainly Nile tilapia *Oreochromis niloticus*) with clariid catfishes (North African catfish *Clarias gariepinus, Heterobranchus bidorsalis,* vundu *H. longifilis*). Brackish-water aquaculture is at a very low level, while mariculture is yet to be developed.

Despite competing needs for organic fertilizers by agriculture, organic manure (mainly chicken droppings) is extensively used for pond enrichment, while the use of chemical fertilizers is limited. Most of the feed ingredients required for the manufacture of livestock and fish feed are locally available. Feed ingredients that are in short supply, such as fish meal, soybean meal and additives, are imported. Feedstuffs are mainly produced in rural areas and distributed to local markets and urban centres by commodity traders.

The review identified a number of unconventional feedstuffs that are important for the formulation and development of cheaper aquafeeds. In 2000/01, approximately 35 750 tonnes of aquafeeds were produced using only 52.4 percent of the installed manufacturing capacity of Nigerian feedmills. Some formulated feeds for high density catfish farming are imported. Most of the 620 feed mills that were operational in 2001 were designed for poultry feed production, while only a few produced aquafeeds as an incidental product. This explains the insufficiency in the supply of good quality aquafeeds and the importation of high quality floating feeds for the early production phase of catfish. There are 10 dedicated aquafeed plants and these are located in Lagos, Ibadan, Jos and Ilorin.

1. INTRODUCTION

The importance of aquaculture in Nigeria has been recognised for many years. Although aquaculture was introduced in the 1950's the sector has only recently made an impact on national fish production. This review is based on secondary-sources of information, a review of the literature, government and NGO reports, contacts and meetings with relevant persons and agencies in Nigeria and visits to fish farmers and feed manufacturers in Lagos.

2. OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

Capture fisheries in Nigeria are more important than aquaculture. In 2004, the total landings from marine and inland capture fisheries amounted to some 465 250 tonnes (FAO, 2006). However, after a series of false starts, aquaculture is now entering an exciting phase of its evolution. It is widely recognized that the progressive development of aquaculture is essential if the projected annual fish demand of 1.5 million tonnes is to be met. Current total fish production from capture fisheries and aquaculture is in the region of 0.5 million tonnes. Moreover, there is a growing recognition of the considerable potential of small-scale aquaculture, which may diversify farmer livelihoods and increase income, while simultaneously reducing risk and vulnerability to food insecurity. In 2004, annual aquaculture production in Nigeria was estimated at 43 950 tonnes (Table 1).

A wide variety of production systems such as ponds, tanks and raceways are used by fish farmers, though earthen pond culture is the dominant system. More recently, fish culture in water recirculation systems has been developed and is being practiced in several urban and peri-urban areas.

Based on the financial disposition of the farmers, aquaculture practices can be classified into large, medium and small-scale businesses. Small-scale fish farmers account for over 70 percent of producers and this group can be further divided into commercial and non-commercial (subsistence) farmers. These farms comprise of holdings ranging from one pond of 0.05 ha to several ponds with a total water surface area of around one hectare. The Nigerian experience serves as evidence that small-holder aquaculture is a cost effective first level solution for fish production (Ayinla and Ajayi, 1996). Feeding practices of the small-scale operators include slight modifications of the culture environment with incomplete control over the environment and the fish. Manure (or compost) is usually added to stimulate primary productivity and low quality feeds such as agricultural by-products (cassava peels, rice bran, etc) and kitchen wastes are applied at irregular intervals. Non-conventional animal protein sources such as maggots and earthworm are also used as supplementary feeds. Stocking density

TABLE 1
Aquaculture production (tonnes) in Nigeria

Species	2003	2004
Tilapias (*Oreochomis niloticus, Sarotherodon galilaeus, S. melanotheron*)	11 363	16 420
Tilapias (*Tilapia zillii, T. guineenis*)	3 025	3 126
North African catfish (*Clarias gariepinus*)	6 553	13 650
Other freshwater catfishes (*Heterobranchus bidorsalis, H. longifilis* and hybrid catfish*)	2 832	3 268
Bagrid catfish (*Chrysichthys nigrodigitatus*)	1 515	1 532
Carps (common carp and Indian major carps)	1 280	1 342
African bonytongue (*Heterotis niloticus*)	654	662
Mullets (*Mugil cephalus, Liza falcipinnis*)	336	345
Snake-head (*Parachanna obscura*)	297	321
Other fishes	2 921	3 394
Total	**30 776**	**43 950**

*Hybrid of *Clarias gariepinus x Heterobranchus longifilis (or H. bidorsalis)*

Source: Federal Departement of Fisheries (2004, pers. comm.)

TABLE 2
Fish production in medium-scale production systems

Culture system	Environment modification	Types of feed	Species	Stocking density (fish/m^3)	Production (tonnes/ha/year)
Integrated pond culture with poultry	Paddle wheel for aeration	Locally pelleted feed	Polyculture (*C. gariepinus & O. niloticus*)	10–15	10–15
Fertilized pond culture (mainly chicken manure)	Stagnant water in earthen pond	Locally pelleted feed	Polyculture (*C. gariepinus & O. niloticus & Heterotis niloticus*)	5–10	5–8
Water recirculation or flow through tank culture	Concrete tanks 10 m^3–15 m^3 with water flow through system	Mainly locally pelleted feed, some farmers use imported feed as starter and local feed as finisher	Monoculture (*C. gariepinus)*	20–25	25–50
Water flow through system in earthen pond	Earthen ponds	Locally pelleted feed and fertilization with chicken manure	Polyculture (*O. niloticus & C. gariepinus*)	10–15	10–12

Source: Oguntade *et al.* (2005)

TABLE 3
Commonly cultured fish species in Nigeria

Species	Relative importance	Environment	Culture System
North African catfish, *Clarias gariepinus*	+++	Freshwater	Polyculture in earthen ponds with tilapia and monoculture in recirculation systems
Nile tilapia, *Oreochromis niloticus*	+++	Freshwater	Polyculture
Gymnarchus atlanticus	++	Freshwater	Polyculture with tilapia
Heterobranchus spp.	++	Freshwater	Polyculture with tilapia
Hybrid catfish*	++	Freshwater	Polyculture with tilapia
Bragrid catfish*, Chrysichthys nigrodigitatus*	+	Brackish water	Polyculture with tilapia
Common carp, *Cyprinus carpio*	+	Freshwater	Polyculture with tilapia
African bonytongue, *Heterotis niloticus*	+	Freshwater	Polyculture with tilapia
Flathead mullet*, Mugil cephalus*	+	Brackish water	Polyculture with tilapia
Nile perch, *Lates niloticus*	+	Freshwater	Polyculture with tilapia
Aba*, Gymnarchus niloticus*	+	Freshwater	Polyculture with tilapia
Tilapia*, Tilapia guineensis*	+	Brackish water	Polyculture with mullet
Tarpon*, Megalops atlanticus*	+	Brackish water & freshwater	Polyculture with tilapia

* Hybrid of *Clarias gariepinus x Heterobranchus longifilis (or H. bidorsalis)*
+++ Highest preference for culture, ++ Moderate preference + Lowest preference
Source: Author's database (2005)

ranges from 1–2 fish/m^2 and yield from 1–2 tonnes/ha/year. The most common species used by small-scale fish farmers include African bony tongue, North African catfish and Nile tilapia. Medium-scale fish farming enterprises contribute between 10–20 percent of the total aquaculture production. These enterprises mainly use concrete tanks for intensive catfish culture and/or earthen ponds (2–10 ha total surface area). The farms are sometimes complemented by a medium sized hatchery and feedmill. Management practices show a greater level of environmental control. Ponds are generally fertilized with manure and the fish are fed on farm-made feeds or locally produced, complete, pellets. Stocking densities in these systems range from 4–20 fish/m^2 with production levels of 4–20 tonnes/ha/year and a culture period of 9–12 months. Table 2 summarizes the practices in medium-scale production systems. The species produced by these farmers include *O. niloticus, C. gariepinus* and *H. bidorsalis*. Large-scale fish farms, of which there are approximately 50 in the country, are enterprises covering 15 ha or more and they account for 5–10 percent of aquaculture production. They normally have around 20 to 30 ponds (nursery and production ponds), a hatchery and a feedmill to supply the required inputs. The high density, water recirculation systems, with fish yields ranging from 10–50 tonnes/ha/year also fall within this category.

Many fish species are cultured in Nigeria. The major groups of economic importance are shown in Table 3. Brackish-water aquaculture, with a production of around 2 000 tonnes/year, is not of any economic consequence.

3. ANALYSIS OF FERTILIZERS AND FEEDS

3.1 Fertilizers

Organic manure is extensively used to enhance pond productivity and plays a much greater role in pond aquaculture than inorganic fertilizers. While all major manure types are available, chicken manure is preferred due to its availability and because there are no religious restrictions to its use in crop and fish production. The recommended application rates of animal manure in Nigeria are; pig manure 560–1 630 kg/ha/week, poultry manure 112–224 kg/ha/week and cattle manure at an average of 672 kg/ha/week.

The most commonly used inorganic fertilizers in Nigerian aquaculture are super phosphate, triple super phosphate, urea, ammonium nitrate, potassium nitrate and potassium sulphate. Phosphate fertilizers are commonly used in ponds because plankton growth is limited by phosphorus. Fertilizer is usually applied at least two weeks after the flooding of a limed pond. It must be emphasized that inorganic fertilizers are in short supply because of the high competition with crop production and are expensive. In 2005, the price of NPK fertilizers was approximately US$600/tonne and the bulk of the supply is normally allocated to crop farmers. Inorganic fertilizers, when available, are therefore normally used on an alternate basis with organic manure.

3.2 Feed ingredients

Intensive and semi-intensive aquaculture depends on formulated feeds, either as a supplement to natural food generated by high pond fertilization rates or as a complete diet (in mash or wet or dry pellet form). Fish feeds generally account for approximately 60 percent of the variable production cost in intensive systems in Nigeria. The cost of feed ingredients is high (Table 4) and competition from other sectors is intense. For commercial production, ingredients are procured in bulk by commodity traders. For farm-made feeds farmers normally buy the feed ingredients directly from the producers, thereby cutting out the middle-man.

The ingredients shown in Table 4 are available all year round but, because of the prevailing agricultural calendar, are relatively cheaper from December to January and more expensive from April to September. Most of the crops are planted in April to October coinciding with the rainy season and harvested in November/December annually. The production of cost effective feeds is predicated by availability, cost and accessibility to ingredients and the protein content of the feed. The ingredients most commonly used in fish feeds are described below.

TABLE 4
Availability and price of local feed ingredients in Nigeria, 2005

Ingredient	Available volumes (tonnes)	Retail price (US$/tonne)	Availability	Producer price (US$)
White maize	6 100 000	340–350	Adequate	250–270
Yellow maize	3 500 000	340–360	Adequate	250–270
Blood meal	70 000	320	Adequate	100–200
Groundnut oilseed cake	720 000	320–340	Adequate	260–280
Cotton oilseed cake	582 000	300–310	Adequate	*
Palm kernel cake	452 320	60–80	Adequate	40–45
Soybean local	90 250	450–470	Low	*
Fishmeal	220 360	870–1 350	Low	*

* =No data

Source: Author's market survey in Lagos (2005)

3.2.1 Fishery by-products

Fishmeal

Approximately 80–90 percent of the artisanal and industrial marine and inland fisheries catch is used for human consumption. The remainder as well as fish offal (heads and tails) from processing factories and trash fish is processed into fishmeal (at cottage level). Local fishmeal production is minimal and cannot meet the demand of the feed industry and hence the bulk of the country's fishmeal requirement is imported. In 2000, an estimated 65 253 tonnes of fishmeal was available in Nigeria, of which 13.4 percent was locally produced and the rest imported, mainly from Norway and Denmark (Fagbenro and Adebayo, 2005). In 2000, there was only one operational commercial fishmeal processing plant in Nigeria, which in that year produced over 8 000 tonnes of fishmeal (Fagbenro, Adeparusi and Fapohunda, 2003). This company has since closed down because the cost of fishmeal production was higher than the imported product. In 2004, the cost of imported fishmeal ranged from US$870–1 350 per tonne, while the cost of locally produced fishmeal was US$1 500 per tonne.

The escalating price of fishmeal, coupled with its scarcity, has stimulated research into ways of replacing fishmeal with other high protein ingredients. However, the inclusion of fishmeal (at up to 25 percent) is still necessary for all stages of intensive *Clarias gariepinus* culture. The proximate composition of the different local fishmeal varieties and other meals of marine animal origin is presented in Table 5.

Nigeria's small-scale fishmeal industry could possibly be expanded by developing a fishery for the unexploited lantern fish resources in national waters and investing in fishmeal manufacturing plant. However, this would only be possible after a comprehensive stock assessment of the resource.

Shrimp head meal

Shrimp, *Penaeus notialis* are caught, processed and packed headless for export. Un-decomposed heads are dried and milled and used as an ingredient for fish feeds, however, only farmers in coastal states have access to this commodity. It is included at 5–10 percent in fish feeds (A. Oresegun, pers. comm.). Annual shrimp production is estimated to be 72 000 tonnes, from which 34 000 tonnes of wet waste is generated, resulting in a production of some 8 820 tonnes of dry shrimp head meal. It is primarily used as an attractant and secondarily as a protein source. It is also used by poultry feed producers. Apparent digestibility coefficients of shrimp head and other commonly used feed ingredients for African catfish are shown in Table 6.

Fish silage

Fish silage can be used to replace fishmeal in the diet of *Clarias gariepinus* (Ayinla and Akande, 1988; Fagbenro and Jauncey, 1994, 1995; Fagbarno, Jauncey and Hayler, 1994). Excellent apparent digestibility of silage based diets has been reported for *Oreochromis niloticus* (Fagberno, 1994; Fagbarno, Jauncey and Hayler, 1994). The application of these findings in practical feed formulation is however limited in view of

TABLE 5
Average proximate composition of selected animal by-products

By-products	Moisture	Crud protein	Crude lipid	Crude fibre	NFE	Ash	Ca	P
Fishmeal (tuna)	7.0	59.0	6.9	0.8	4.4	21.9	7.9	4.1
Fishmeal (tilapia)	10.8	57.7	1.8	5.2	-	33.6	8.5	5.1
Fishmeal (clupeid)	9.8	71.3	8.0	1.1	-	20.2	3.6	2.2
Fishmeal (clupeid)	9.8	68.5	8.0	0.4	-	17.8	2.3	1.6
Crab meal	9.1	31.7	2.4	-	10.5	46.2	-	-
Cray fishmeal	15.0	41.2	11.7	-	0.4	31.7	-	-

NFE = Nitrogen free extract

Source: Eyo (1999); Ayinla (1991)

TABLE 6
Mean apparent digestibility coefficient (%) of various feedstuffs for catfish, *Clarias agboyiensis* fingerlings - data are presented as the mean and range in parenthesis

	Apparent digestibility coefficient (%)		
	Dry Matter	**Crude protein**	**Gross energy**
White fishmeal	85 (82–88)	82 (81–83)	93 (89–98)
Poultry by-product meal	70 (68–74)	79 (74–81)	85 (84–87)
Hydrolyzed feather meal	63 (61–65)	85 (82–87)	78 (75–81)
Bloodmeal	69 (68–70)	77 (74–78)	67 (64–71)
Shrimp head meal	77 (73–80)	90 (87–92)	59 (57–64)
Meat and bone meal	65 (62–67)	68 (63–71)	74 (72–75)
Soybean meal	67 (66–71)	90 (88–93)	85 (83–87)
Cottonseed meal	50 (46–54)	76 (75–77)	70 (68–72)
Peanut meal	58 (52–64)	75 (72–80)	66 (63–69)
Yellow maize	40 (39–42)	92 (90–93)	58 (56–61)
Corn starch	45 (41–47)	–	86 (84–88)
Cassava meal	40 (35–43)	–	74 (73–76)
Sorghum	39 (32–41)	58 (50–61)	49 (48–50)
Rice bran	38 (37–40)	75 (74–76)	53 (50–55)
Cocoa pod meal	36 (33–43)	79 (76–81)	50 (47–53)

Source: Fagbenro, Adeparusi and Fapohunda (2003)

the complex processing procedures and associated high costs, hence it is not used as a major ingredient in commercial aquafeeds.

3.2.2 Terrestrial animal by-products

Abattoir by-products

Approximately 50 000 tonnes of bloodmeal is produced annually (Fagbenro and Adebayo, 2005), however the potential of abattoir wastes such as carcass, blood and bonemeal for aquafeed production has been largely neglected. Bloodmeal contains about 80 percent crude protein, though the local processing methods affect lysine availability. The local bloodmeal is also deficient in isoleucine, cystine and tryptophan (Eyo, 2003). It is widely used by small-scale fish farmers, whereas its use by larger commercial farms is negligible (personal observation). The use of bonemeal as a mineral source is limited to farm-made feed producers and most of the commercial aquafeed producers use imported vitamin and mineral premixes.

3.2.3 Oil seed cakes

Oilseed cake meals comprise the major plant protein constituents of fish feeds in Nigeria.

Copra meal

It is obtained from coconut milling. The extraction of the oil produces copra / coconut meal. It is fairly high in protein (21 percent) (Adikwu, 2003), is available all year round and relatively cheap (US$0.30/kg). It can be used at a moderate level of inclusion to replace all brewers dried grain and / or palm kernel cake in tilapia feeds.

Groundnut cake

Annual groundnut production is around 1.8 million tonnes, from which approximately 632 750 tonnes of cake is produced for domestic animal feed production. It has a crude protein content of 40–45 percent. However, due to a high demand for human consumption and for livestock feeds the price is high (US$320–340/tonne). It is widely used in aquafeeds throughout Nigeria.

Cotton seed cake

Cotton seed cake is used mainly as a protein source in fish feeds by small-scale producers. It is relatively low in cystine, methionine and lysine as well as calcium (Eyo, 2003). It is a good substitute for groundnut cake in the diet of *Clarias gariepinus*. There are many cotton seed crushers in northern Nigeria. The annual processing capacity is 520 160 tonnes. Nigeria exports cotton oilseed cake mainly to Egypt and South Africa (Fagbenro, Adeparusi and Fapohunda, 2003).

Sesame seed cake
Sesame is widely cultivated in the north, central and north eastern states of Nigeria and approximately 40 000 tonnes are produced annually (Fagbenro, Adeparusi and Fapohunda, 2003). The cake contains 35–40 percent protein and is high in methionine and tryptophan, but limited in lysine. It contains niacin, which is not found in soybeans and is also rich in linoleic acid, vitamin E and vitamin A, B, B2 and does not contain any anti-nutrient factors. Despite the fact that it can fully replace soybean meal and partly replace fishmeal, it is not widely used in aquafeeds in Nigeria (Eyo, 2003).

Palm kernel cake
This is the by-product of oil extraction from palm kernels. In rural areas, small-scale farmers use the cake to feed tilapia and catfish in powder form, along with chicken manure pond fertilization. Approximately 774 000 tonnes of African oilpalm nuts were produced in 2001 (Fagbenro, Adeparusi and Fapohunda, 2003), from which over 400 000 tonnes of palm kernel cake is produced for the animal feed industry (Fagbenro and Adebayo, 2005). The cake has a crude protein content of 19 percent and high fibre content (14.7 percent) and hence its inclusion level in fish feeds is less than 10 percent.

Soybean meal
Soybean meal is a major protein source for commercial feed production in Nigeria. It is rich in lysine and low in methionine. It contains all other essential amino acids and is often combined with fishmeal and other plant protein sources in commercial feed rations. Because soybeans are also consumed by humans, the price is high. The local production of 255 200 tonnes falls short of the required 750 000 tonnes, hence Nigeria is a net importer of soybeans (Fagbenro, Adeparusi and Fapohunda, 2003) and, in 2004, 550 000 tonnes of soybean meal was imported (LASADA- pers. comm.). The anti-nutrient factors of soybeans are effectively destroyed by controlled heat treatment (roasting, parboiling and extrusion) (Eyo, 1999; Balogun and Ologhobo 1989; Fagbenro and Davies, 2003). Soybean oil is not produced in Nigeria; hence full fat soybean meal is used in aquafeeds.

3.2.4 Oils
The oils used for animal and fish feed production are listed in Table 7, together with prices and relative availability. Corn oil is most commonly used for commercial fish feed production.

TABLE 7
Fish and vegetable oil availability and price

	Price (US$/litre)	Availability
Fish oil (imported)	3.50–4.00	Scarce
Palm oil	1.10–1.20	Adequate
Groundnut oil	1.60–1.80	Adequate
Soybean oil	1.40–1.50	Adequate
Coconut oil	2.20–2.40	Scarce
Corn oil	1.35–1.40	Scarce
Olive oil (imported)	1.00–1.20	Scarce
Mixed vegetable oil	1.10–1.15	Low

Source: Fagbenro and Adebayo (2005)

3.2.5 Cereal grains and by-products
Total grain production in 2000 was a little over 35 million tonnes, comprising maize, sorghum, millet, rice and wheat (Fagbenro, Adeparusi and Fapohunda, 2003). The proximate composition of local cereals grains and their by-products is shown in Table 8. Sorghum and millet can be used as alternatives to maize as energy sources in aquafeeds (Table 9).

TABLE 8
Proximate composition (% as fed basis) of cereal grains and by-products

Feedstuff	Moisture	Crude protein	Crude lipid	Crude fibre	NFE	Ash
White maize	8.6	9.3	5.0	2.4	70.9	1.7
Yellow maize	9.6	10.1	3.6	3.5	71.2	0.2
Guinea corn	11.2	11.2	2.5	2.3	74.1	1.8
Millet	8.7	4.8	1.3	38.3	41.2	5.7
Rice bran	–	6.9	4.4	40.2	6.7	21.8
Sorghum	12.0	7.8	4.8	7.6	65.7	2.1

NFE=Nitrogen free extract

Source: Eyo (2003)

TABLE 9
Conventional and alternative ingredients and their maximum recommend inclusion rates

Nutrient	Conventional feedstuffs	% of feed	Alternative feedstuffs	Maximum inclusion (%)
Protein	Fishmeal	40	Groundnut cake	25
	Soybean meal	45	Palm kernel cake	15
			Cottonseed cake	20
			Jack bean	10
			Poultry offal	10
Energy	Maize	50	Sorghum	50
	Cod liver oil	10	Cassava	40
			Sweet potato	20
			Corn oil	10
			Soybean oil	10
			Palm oil	10
Minerals	Oyster shell	7.5	Periwinkle shell	7.5
	Bone meal	2.5	Limestone	5
	Dicalcium phosphate	2.5	Malt dust	2
			Common salt	2
Additives	Vitamin premix	1		
	Mineral premix	1		

Source: Fagbenro, Adeparusi and Fapohunda (2003)

3.2.6 Brewery by-products

The most important by-products of the brewing industry are brewers' wet waste, dried grains and maize grits. Brewers dried grain is the extracted residue of fermented barley or barley mixed with other cereals. It is low in energy but high in fibre. Only limited quantities are available and it is included into fish feeds at 5 percent or less. Corn grits are the medium sized, hard, flinty portions of ground corn, containing little or none of the bran or germ. Production of this by-product is increasing as a consequence of the malt importation ban. Corn grits could replace 25–50 percent of cereals in fish feeds, which would significantly reduce the cost of feed.

3.2.7 Flour milling by-products

Wheat bran and wheat middlings are the major by-products. Wheat bran is high in fibre, which limits its inclusion level in most aquafeeds, with the exception of tilapia feeds. It is high in niacin. Wheat middlings, although having higher protein content than wheat bran, is also fibrous and is included at 10 percent in tilapia feeds.

3.2.8 Starch roots and tubers

Root crops (cassava, yam, potato) constitute the main staple foods in Nigeria. Nigeria has become the world's leading producer of cassava (30 million tonnes in 2004). It is estimated that cassava peel, leaves, pomace from starch and garri (cassava flour) residues amount to some 6 million tonnes (Fagbenro, Adeparusi and Fapohunda, 2003). Some of these by-products are either fed directly to fish in ponds or used in aquafeed production at an inclusion level of 10 percent or less.

3.2.9 *Non-conventional feed resources*

The high price of compounded feeds (Table 10) is a major constraint to fish farmers (Ayinla and Bekibele, 1992; Ayinla and Ajayi, 1996). Other cheaper resources, not used for human consumption, have therefore been identified, explored and tested as fish feed ingredients. However, these non-conventional resources, of either animal or plant origin, are uncommon on the market and are therefore not readily available to larger feed manufacturers.

Some of the non-conventional fish feed ingredients of animal origin include: maggots, termites, earthworms, chicken offal, hydrolyzed feather meal and toad meal. The proximate composition of some of these is shown in Table 11 and several can readily be included into aquafeeds (Table 12). However, because of the high production costs their use in commercial aquafeed production is limited (Bekibele, Wuyep and Ayinla, 2000).

TABLE 10
Price of some aquafeeds in comparison to chicken and pig feed

Feed type	Price (US$/kg)
Aquafeed	
4 mm grow-out (floating pellet, imported)	1.50
4 mm grow-out (floating pellet, local)	1.30
4 mm grow-out (farm-made sinking pellet)	1.10
2–3 mm juvenile feed (floating pellet for catfish, imported)	3.00
0.2–0.3 mm fingerling feed (floating pellet for catfish, imported)	3.00
0.3–0.5 mm fingerling (floating pellet for catfish, imported)	3.00
1.0–1.2 mm juvenile (floating pellet for catfish, imported)	3.50
2 mm grow-out (floating pellet, imported)	1.50
Mash for farm-made feeds for polyculture of tilapia and African catfish	0.60
Chicken feed	
Starter mash	1.20
Grower mash	0.80
Finisher mash	1.00
Pig feed	0.50

Source: Lagos market survey (2005)

TABLE 11
Proximate composition (% fresh weight/as fed basis) of aquatic and terrestrial plants and animals

Feedstuffs	Moisture	Crude protein	Crude lipid	Crude fibre	NFE	Ash
Aquatic fern (*Azolla* sp), fresh	93.5	1.7	0.3	0.6	3.2	0.1
Aquatic fern (*Azolla* sp), dry	-	25.3	3.8	2.3	49.1	12.5
Water hyacinth (*Eichhornia crassipes*), fresh	91.5	1.2	0.3	1.9	3.8	1.3
Water hyacinth, dry	10.5	14.2	1.3	9.4	20.0	44.6
Water lettuce (*Psitra stratisles*), fresh	93.6	1.2	0.3	1.0	2.0	1.6
Water lettuce, dry	-	15.9	4.2	20.8	36.1	23.0
Maggot, dry	9.3	43.8	1.9	14.3	22.3	14.3
Earthworm, dried	5.0	56.4	7.8	1.6	25.4	8.8
Chicken offal, dried	8.6	47.5	22.8	5.0	6.1	10.9
Chicken offal, cooked & dried	8.3	61.6	16.5	3.5	2.2	9.0
Toad meal, dried	5.4	59.3	11.5	0	5.3	18.5
Hydrolysed feather meal	8.1	84.2	2.8	1.0	0.5	3.4
Mucuna feed meal	-	32.1	4.6	6.9	54.1	2.3
Mango kernel meal	-	10.3	10.9	2.0	68.0	2.6
Cocoa cake, defatted	12.9	24.9	5.0	9.0	42.1	6.1
Bloodmeal	11.8	86.0	0.7	2.1	6.5	5.2

Source: Tacon (1987); Ayinla (1991); Joseph and Abolaji (1997); Bekibele, Wuyep and Ayinla, 2000; Eyo (2003); Siddhuraju and Becker (2001); Faturoti (2002); Madu and Ufodike, (2003)

TABLE 12
Unconventional feedstuffs and their optimum inclusion levels in aquafeeds

Feedstuff	Fish species	Maximum inclusion rate and ingredients/nutrients substituted
Jackbean (*Canavalia ensiformis*)	C. gariepinus	15–30% (replacement of soybean meal)
Fish silage	C. gariepinus	41% (replacement of fishmeal)
Shrimp head meal	C. gariepinus	10% (replacement of fishmeal)
Mango kernel	Labeo senegalensis	Replacement of protein 10% unprocessed or 20% boiled
Duck weed	S. galilaeus	15% (replacement of carbohydrate source)
Winged bean (*Psophocarpus tertragonolobus*)	C. gariepinus	50% (replacement of fishmeal)
Macadamia presscake	O. niloticus	50% (protein)
Poultry by-product silage meal	C. gariepinus	15–30% (protein)
Poultry viscera silage meal	C. gariepinus	15–30% (protein)

Source: Ayinla and Akande (1988); Mbagwu, Okoye and Adeniyi (1990); Balogun and Fagbenro (1995); Fagbenro and Fasakin (1996); Joseph and Abolaji (1997); Fagbenro (1999); Alegbeleye, Oresegun and Ajitomi (2001)

3.3 Aquafeed production

3.3.1 Commercial aquafeed production

Aquafeed production is a recent initiative and since 2000 has mirrored the upsurge in commercial fish farming. There are at least 10 commercial aquafeed producers and a new factory with a capacity of 13 000 tonnes per annum has recently been commissioned in Ilorin, Kwara State. In addition, a foreign company is planning to establish in Lagos an aquafeed production unit, with an annual capacity of 15 000 tonnes. There is one industry that has the necessary infrastructure to produce extruded floating pellets and has recently started producing extruded floating pellet on pilot scale with a production capacity of 6 tonnes per day (Hasan, 2005) (Figure 1). All of the commercial feed producers target the needs of catfish farmers. However, specifically formulated and extruded pellets for the early rearing stages of *Clarias gariepinus* are imported from Aquanutro (Pty), Ltd in South Africa.

Shipton and Hecht (2005) reported that Nigeria has 620 animal feed manufacturers with an installed capacity of 7.25 million tonnes per year, producing approximately 3.8 million tonnes annually. The majority of feedmills are small and produce between 0.5–5.0 tonnes/hour. As previously mentioned, poultry feed production is the major animal feed business, although now there is a trend for these mills to install pelletizers and dryers to produce fish feeds. Currently (2006) there are some 32 larger feed producers and around 500 smaller producers (O.A. Fagbenro, pers. comm., 2006).

FIGURE 1
Extruded floating pellet produced by CHI Industries Ltd., Ibadan, Oyo State

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Based on data for 2001, Shipton and Hecht (2005) projected (on the basis of a 10 percent growth rate) that Nigeria would produce some 128 559 tonnes of fish by 2015. The probability of surpassing this projected production level is high in view of unprecedented private sector participation and investment in aquaculture. Furthermore, the Federal Government has put in place intervention programmes such as the Special Programme for Food Security (NSPFS) with a focus on private sector participation in the promotion of food production (aquaculture inclusive). Each state of the federation promotes aquaculture in various ways. This will add enormous pressure on the production of adequate quantities of fish feeds.

Until very recently feed millers produced a general purpose fish feed with crude protein content ranging from 15–30 percent. Aquafeed

TABLE 13
Fish feed production (tonnes) in Nigeria in 2000/01

Fish species	Farm-made	Commercial	Total
Tilapia	14 258	6 554	20 812
Catfish	10 552	4 206	14 758
Total	**24 810**	**10 760**	**35 570**

Source: Fagbenro and Adebayo (2005)

TABLE 14
Some feed formulations for catfish and tilapia in Nigeria (% dry matter basis)

Ingredient	Catfish feeds (40% CP)		Tilapia feed (30% CP)
	Grower	Broodstock	
Fishmeal (65% CP)	25	25	15
Soybean meal (45% CP)	35	35	45
Maize	15	10	25
Bloodmeal (85% CP)	10	10	-
Fish oil	6	9	4
Vegetable oil	4	6	6
Vitamin and mineral premix	3	3	3
Binder	2	2	2

CP=crude protein

Source: Fagbenro, Adeparusi and Fapohunda (2003)

production in Nigeria is summarized in Table 13. It was not possible to obtain accurate figures for imported fish feeds. The upsurge of interest in fish farming, in general, and intensive culture of *C. gariepinus* in particular, has stimulated the production of specific tilapia and catfish feeds (Table 14).

The price of catfish grow-out feed has increased form US$0.50–1.00/kg in 2000, to between US$0.60–1.50/kg in 2004. The highly variable prices are a consequence of fluctuations on the international commodity markets and the fluctuating rate of the local currency.

3.3.2 Farm-made feed production

Some small-scale farmers, particularly in rural areas, still adopt traditional feeding methods using cassava peels, palm fruits, household waste, pawpaw leaves and corn wastes. However, in view of the general awareness of the importance of feeding fish to enhance production these practices are slowly disappearing. Many small-scale farmers now compound their feeds using locally available ingredients such as rice bran, corn meal, bloodmeal, brewers waste, groundnut cake, palm kernel cake etc. These feedstuffs are ground separately, weighed and mixed according to specific formulations. Many farmers feed the formulated mash directly, while others manufacture their own pellets or moist feed balls (see later). Corn or cassava starch is used as a binder.

All medium and large-scale fish farmers use sinking or floating pellets with FCRs of 1.5 to 2.5:1, depending on the level of management. Most of the successful medium and large-scale farmers have their own small feedmills, which enable them to control their production systems and cycles. The machinery used ranges from adapted poultry feed machinery, locally fabricated pelletizers to imported hammer mills, mixers and pelletizers. Many successful fish farmers also produce chickens and use the innards and other offal as ingredients for farm-made aquafeeds. This has significantly reduced their feed costs and some reportedly spend US$0.30 as feed input to produce a kilogramme of fish, which sells at US$2.00 (Hammed, pers. comm.). However, these are exceptional cases.

The process of manufacturing farm-made feeds in Nigeria is as follows. After heating or cooking the ingredients, to destroy the anti-nutrient factors and to improve digestibility, they are cooled and milled (Figure 2a). The ingredients are compounded and mixed, either by hand or mechanically in simple mixers such as a concrete mixer (Figure 2b). Hot water is then added and the mixture is kneaded into dough. Cassava or corn starch is added as a binder if the cereals are not sufficient to bind the particles. The dough is then passed through a meat mincer (Figure 3) or perforated metal sheets to form moist "spaghetti" like strands, which are either fed to the fish in the moist form or are sun dried, by placing them on corrugated iron sheets or using home made or locally manufactured electric dryers (Figure 4).

FIGURE 2
Local grinder used for grinding feed ingredients (left) and cement mixer adapted for feed mixing (right)

One of the major problems in the use of farm-made feeds is the short shelf life of the feeds and this is mainly because farmers do not use any anti-oxidants. Inadequate storage also results in insect and rodent infestation. Most aquafeed producers in Nigeria are not conscious of these problems hence the careless method of packaging and storage of feed. To improve the shelf life of feed some producers have recently started using sodium propionate at an inclusion level of 0.1 percent as an anti-fungal agent.

FIGURE 3
On-farm pelleting process using a meat mincer

Feed formulations vary according to the availability of ingredients. Some of the on-farm formulations for catfish and tilapia are shown in Table 14. Vitamin premixes commonly used by the poultry industry are also used in the manufacture of fish feeds. In the absence of premixes, vitamins are provided by the addition of milk, liver, kidney, yeast, egg, green vegetables, fruits and poultry viscera.

FIGURE 4
Sun drying of pelleted feed on top of concrete ponds (left) and a locally fabricated electric dryer (right)

3.4 Feeds, feeding frequency and ration

As previously indicated, fish farmers use a vast variety of feeds, ranging from non-conventional ingredients to extruded floating pellets. The small-scale, largely subsistence, farmers mainly rely on natural pond productivity and occasional supplementary feeding with single, low nutrient, feeds such as rice or maize bran. This practice is being rapidly replaced by more scheduled feeding practices. The following feeds are used by commercial farmers in Nigeria.

Extruded floating pellets: Imported extruded floating pellets have gained popularity among fish farmers engaged in intensive culture of *C. gariepinus*, with FCRs of 0.95 to 1:1. However, because of the high price, imported floating pellets are now only used as a starter feed for the first month of production and thereafter locally manufactured feeds are used for the 4–5 month production cycle. This practice has increased their profit margin. At this stage there is no better alternative feed for the first month of production. These pellets are used only in high density flow-through or recirculation systems.

Sinking pellet: Locally manufactured sinking pellets are commonly used. They are cheaper than the imported floating pellets, but their use requires a greater degree of management. They are widely used in semi-intensive polyculture of *C. gariepinus* and *O. niloticus* in fertilized ponds, with FCRs of 1.6 to 2.5:1 and are also used for grow-out of catfish under high density tank farming conditions (Figures 5 and 6).

Mash: Mash or meals are prepared by grinding or crushing pellets to fine particles (0.35–0.5mm) or by mixing various ingredients to required formulations. Leaching of nutrients is a major problem as they are fed either in a dry form or as dough. These feeds are often used for *O. niloticus* and *C. gariepinus* fingerlings when adequate particle size pellets are

FIGURE 5
Broodstock of African catfish, *Clarias gariepinus* kept in outdoor recirculatory rearing tank and fed with sinking pelleted feed, Ibadan

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FIGURE 6
High density rearing of African catfish in an indoor recirculatory tank. Fish are fed with sinking pelleted diet using a locally manufactured demand feeder, Ibadan

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unavailable and for table fish production in fertilized ponds.

Crumbles: Crumbles are also commonly used for fattening fingerlings to table size fish with FCRs ranging from 3.0 to 3.5:1. They are used in rural areas where there are no facilities for pelleting.

***Artemia*:** *Artemia* nauplii are only used for a few days during the early larval rearing phase of African catfish. All *Artemia* cysts are imported.

Many of the small-scale commercial farmers cannot afford the locally manufactured pelleted feeds, hence the bulk of fish feeds (69.75 percent) are farm-made (dry mash, dough balls and meat mincer pellets, fed in moist or sun dried form). Two main types of feeds are produced commercially, viz. tilapia feeds that contain 25–30 percent crude protein and catfish feeds that contain 40–50 percent protein for the various phases of growth. In view of the recent expansion of intensive catfish farming the commercial feed producers are focusing their efforts on producing improved catfish feeds.

TABLE 15
Fish farm labour requirements in Nigeria

Farm size	Level of intensity	Labour required	Cost implication (US$ per month)
Small (1–2 ponds of 0.1 ha each)	Semi intensive	2	60–70
Small (1–2 ponds or 4–6 tanks of 10 m^3)	Intensive	4	130–140
Medium 3–10 ponds 0.1 ha each	Semi intensive	4	130–140
7–12 tanks of 10 m^3 each	Intensive	6	160–170

Source: Interviews with fish farmers in Lagos and Yola

Feeding rates for fish are either based on percent body weight, or alternatively, they are fed to satiation on an *ad libitum* basis. In most cases 5 percent of the body weight of the standing crop is adopted as a standard for grow-out. Under semi-intensive pond farming conditions the fish are normally fed twice a day, while *C. gariepinus* under intensive culture conditions are fed four to six times per day.

Feed is either applied manually or mechanically. Manual feeding is the most common and popular method and is carried out by broadcasting the feed over the water surface or at established feeding points. Although it is labour intensive, it allows the farmer to observe the feeding behaviour of the fish. Mechanical feeding with demand or automatic feeders is not widely used in Nigeria, except on one or two commercial farms or otherwise on an experimental level.

3.5 Labour

Labour is required for feed preparation, feed application, general pond management and harvesting. The number of labourers required is a factor of farm size and production intensity. A general breakdown of fish farm labour requirements and costs are shown in Table 15.

4. OVERVIEW OF THE ANIMAL FEED INDUSTRY

Livestock and poultry husbandry is widespread in Nigeria. The bulk of the ruminants (cattle, sheep, and goats) depend on rangelands and grazing reserves (Fagbenro and Adebayo, 2005), while pigs are reared using traditional systems or in commercial piggeries. The bulk of the poultry consumed in Nigeria is produced on commercial

TABLE 16
Animal and aquaculture feed production in Nigeria in 2001

Feed type	Quantity (tonnes)	Percent of total
Poultry	2 591 732	68.20
Pig	1 084 214	28.53
Rabbits	88 409	2.33
Fish	35 570	0.94

Source: Fagbenro and Adebayo (2005)

broiler farms, hence the animal feed industry is dominated by poultry feed producers. Animal feed production in 2001 is presented in Table 16.

In semi-intensive and intensive pig and poultry production systems feeds comprise 20–30 percent of the total production cost. Although the production of conventional livestock feeds has risen steadily over the years, the poor distribution channels and feed quality constitute major constraints to the growth and profitability of intensive livestock and poultry enterprises (Fagbenro and Adebayo, 2005). In 2000, the industry's operational production efficiency was 52.4 percent (Fagbenro and Adebayo, 2005).

The animal feed industry in Nigeria is unregulated. There are no quality control standards and there is no animal feed producer association. The total supply of all locally produced feeds does not appear to adequately meet the present demand. This may be due to shortages in the imported supply of fishmeal and soybeans.

The cost of feed commodities reflects free market forces of supply and demand in Nigeria. As a result of the heavy dependence on imported concentrates, fluctuations in prices are common. The cost of feedstuffs also varies due to general inflation, the official regulation of commodity markets by import control subsidies and state purchases of staple feed commodities.

4.1 Problems and constraints

Competition for the use of conventional feed ingredients for human and animal consumption has resulted in significant price escalations. This and the general shortage of fishmeal and soybeans warrant the need for on-going research on alternative ingredients for use in aquafeeds. In particular the research must focus on those commodities that are not in demand for human consumption. Also, there is a need to develop cost effective technologies for the production of non-conventional feed ingredients (e.g. toad and tadpole meal, fish silage). Much work has been done in Nigeria to replace fishmeal with other proteins of plant and animal origin. Protein sources of animal origin include terrestrial and aquatic worms, fish silage, bloodmeal, insect larvae, poultry by-product meal, meat and bonemeal, tadpole meal, while plant protein commodities include jackbean (*Canavalia ensiformis*), algae meals, bambara bean etc. The results range from poor to very good in terms of fish growth and feed conversion efficiency. While unconventional feedstuffs can be used in aquaculture, it seems that the use of fishmeal is largely still indispensable in intensive culture of species such as *C. gariepinus*. With the long-term aquaculture production target of 2 million tonnes, the demand for aquafeed will be around 4 million tonnes. It is therefore vital for the feed industry to become better organized and regulated.

There are other problems that also constrain the animal feed industry. For example, the lengthy customs clearing process often results in spoilage of ingredients. If this problem is not addressed and resolved it will severely constrain the development of urban and peri-urban aquaculture in the country. Clearly, there is a need for the Federal Government to assess the needs and constraints faced by the sector and to develop the necessary institutional platforms for aquaculture to expand such that the production targets can be met.

Despite the relatively good road and transport network, farmers in rural areas are constrained by the supply and cost of feed. While some still use "junk food", such as kitchen waste, brans and other farm residues, many fish farmers now source ingredients directly from the producers and make their own farm-made feeds. It is estimated that close on 70 percent of all aquafeeds presently used in Nigeria are compounded, farm-made feeds.

5. RECOMMENDATIONS

- Contrary to other countries in sub-Saharan Africa, aquaculture in Nigeria is a private sector driven initiative. The rapid growth of the sector in Nigeria has given rise to several problems that now constrain its expansion. In particular, these constraints revolve around the issue of feeds.
- For the sector to expand and to reach its production targets there is a need for the Federal Government to assess and identify the needs of the sector and the constraints faced by fish farmers and to develop appropriate institutional platforms and incentives to promote its rapid development.
- There is a need for the government to develop an animal feeds policy and to promulgate an animal feeds act, so that the feed industry can be regulated to assure the supply of quality feeds.
- There is a need for feedmills to improve their storage facilities to stockpile materials and for the industry to supply the market with better quality feeds.
- Given the dependency of the country on soybean imports, Nigeria should examine and provide incentives to promote soybean farming.
- There should be a greater emphasis on research into anti-nutrient factors in pulses, which are plentiful in Nigeria, e.g. jackbean, mucuna, bambara beans etc.
- A nutrient master plan must be developed to facilitate the development of small-scale, rural aquaculture. This plan should consist primarily of an inventory of locally available, conventional and non-conventional, feedstuffs and their proximate and chemical composition. This will allow for the formulation of "regionally specific fish rations".
- Incentives should be provided by the Federal Government for the importation of feed manufacturing equipment and raw materials to encourage investment in aquafeed production.
- A comprehensive stock assessment of lantern fish in Nigeria's exclusive economic zone should be undertaken. If the stocks are found to be economically viable then the government should promote the development a reduction fishery, such that the country becomes less reliant on fishmeal imports.

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Analysis of feeds and fertilizers for sustainable aquaculture development in Uganda

J. Rutaisire
Department of Wildlife and Animal Resources
Makerere University, Kampala
Uganda

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SUMMARY

This paper reviews the current status of feed and fertilizer use in aquaculture in Uganda. Aquaculture in Uganda is still largely at a subsistence level despite having been practiced for more than 50 years. However, there have been some significant changes since the late 1990s. Sixteen species have been tested for farming in Uganda, but only four (Nile tilapia *Oreochromis niloticus*, redbelly tilapia *Tilapia zillii*, common carp *Cyprinus carpio* and North African catfish *Clarias gariepinus*) are cultured. These species are reared mainly under polyculture conditions in earthen ponds. Monoculture is restricted to North American catfish fingerling production, which are used as live bait in the Nile perch, long line fishery in Lake Victoria.

The majority of small-scale subsistence farmers rely on organic fertilization of ponds and the provision of green leafy materials regardless of whether the fish are herbivorous or not. Cattle and pig manure are available free of charge, whilst chicken manure is available at a relatively cheap price. Supplementary feeds are normally provided by broadcasting the feed, such as rice or maize bran, over the pond surface. All commercial and emerging commercial farmers feed their fish according to specific protocols. Commercial farmers make their own feeds and some produce their own pellets. Commercial fish feeds are not readily available. Only one feed producer makes a sinking pellet, the performance of which still has to be evaluated.

Availability and price of feed ingredients is determined by the agricultural calendar. Transport costs are high, and this affects feed prices. The proximate composition of local feed ingredients is known. Fishmeal is not imported into Uganda and the bulk of the fishmeal is made from the pelagic minnow (silver cyprinid *Rastrineobola argentea*), the second most important commercial fish species in Lake Victoria The country's climate and soils favour large scale production of soybeans and this should be strongly promoted.

On the whole, the major constraints facing the development of the aquafeed industry include the lack of prerequisite information, appropriate technologies, affordable credit facilities and poor infrastructure. However, the current positive trends in aquaculture development, exhibited by substantial private sector investment and an enabling policy framework are indicative of the viability and potential of aquaculture in Uganda.

1. OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

Aquaculture in Uganda began in 1953 with the establishment of the Kajjansi experimental station of Aquaculture Research and Development Centre (ARDC). Despite its long history the sector has largely remained at a small-scale, subsistence level. The contribution by aquaculture to national fish supply is insignificant. There are approximately 7 152 fish farmers in Uganda with about 30 000 ponds (UBOS, 2004). The average pond size is 222 m^2 and average production has been estimated at 1 800 kg/ha/year (NARO-MAIIF, 2002). Total fish production in 2003 was 5 500 tonnes (FAO, 2005). However, since the late 1990s aquaculture in Uganda has changed rapidly due to the greater interest and participation by the private sector. Several commercial fish farms are emerging in the country and these are targeting the regional table fish market as well as the baitfish market. This is in line with the Government's Plan for Modernisation of Agriculture (PMA).

The recent renewed interest in aquaculture is mainly attributed to the advances in North African catfish *(Clarias gariepinus)* culture. Due to its desired qualities the African catfish has become one of the key aquaculture species in Uganda and is likely to become the main contributor to aquaculture production both in terms of volume and value. Polyculture of North African catfish with Nile tilapia (*Oreochromis niloticus*) has also resulted in the production of larger size fish. The size of table fish is very important in Uganda, since fish of less than 300 g are shunned by the consumers. The aquaculture potential of several fish species has been tested at ARDC, Kajjansi and other parts of Uganda but only a few are cultured in the country (Table 1).

TABLE 1
Fish species that have been tested and their current culture status in Uganda

Species	Not currently cultured	Cultured	Remarks
Nile tilapia, *Oreochromis niloticus*		✔	Widely cultured
Victoria tilapia, *Oreochromis variabilis*	✔		Not currently cultured
Wami tilapia, *Oreochromis urolepis hornorum*	✔		Hybridized & disappeared from ARDC, Kajjansi
Blue tilapia, *Oreochromis aureus*	✔		Disappeared from ARDC, Kajjansi
Oreochromis spilurus	✔		
Oreochromis leucostictus	✔		Considered a wild species that contaminated cultured cichlids.
Redbelly tilapia, *Tilapia zillii*		✔	Herbivorous cichlid cultured widely but often stunts in ponds.
Redbreast tilapia, *Tilapia rendalli*	✔		Imported for hybridization experiments at ARDC, Kajjansi but disappeared from the station
Common carp, *Cyprinus carpio*		✔	Cultured and popular in the cooler mountainous parts of the country.
Grass carp, *Ctenopharyngodon idella*	✔		Failed to breed/disappeared from ARDC, Kajjansi
Giant gourami, *Osphronemus goramy*	✔		Bred on their own in ponds but disappeared
Black bass, *Micropterus salmoides*	✔		Did not breed and disappeared from ARDC, Kajjansi
Semutundu, *Bagrus docmak*	✔		Research to breed & culture in captivity on-going
North African catfish, *Clarias gariepinus*		✔	Cultured and popular
Rainbow trout, *Oncorynchus mykiss*	✔		Not cultured but is caught in Mt. Elgon rivers.
Crayfish, *Procambarus clarkii*	✔		Burrows and destroys pond banks. It has therefore been discouraged in aquaculture. It was introduced into Lake Bunyonyi, a crater lake where it supports a fishery.

ARDC=Aquaculture Research and Development Centre
Source: Owori-Wadunde (2001)

NARO-MAAIF (2002) survey revealed that 50 percent of small-scale fish farmers in Uganda make special preparations prior to stocking their ponds. These include draining and drying the ponds to allow mineralization of the accumulated organic matter. The drained ponds are usually de-silted or dredged. A small proportion of farmers (3 percent) lime their ponds. Fourty percent of the ponds are operated on a flow-through system. The majority of fish farmers (70 percent) rely on ground water for filling their ponds. Most farmers mow the grass both on and around pond dykes and protect their ponds from predators and theft. Most subsistence farmers use a mix of species in an unmanaged manner), with stocking densities ranging from 1–3 fingerlings/m^2 (NARO-MAAIF, 2002).

More recently commercial farms, which practise both poly- and monoculture, have started to emerge. Polyculture is mainly undertaken with North African catfish and Nile tilapia in a predator-prey relationship. This has been made possible by the ready availability of seed of both species. Rutaisire (2005) found that the average fish stocking density in African catfish/Nile tilapia polyculture systems is 10 fish/m at a ratio of 6:4, respectively. Monoculture of Nile tilapia is not popular due to its precocious breeding habits and stunting. Monosex culture of Nile tilapia is yet to be developed and promoted in Uganda. Monoculture is mainly practiced with common carp *Cyprinus carpio,* especially in the mountainous cooler regions of the country where temperatures fall below 20ºC. Overall, 57 percent of fish farmers practice polyculture (Nile tilapia and African catfish) and 43 practice some sort of monoculture (NARO-MAAIF, 2002). The production of African catfish fingerlings is increasing, particularly for live-bait in the Nile perch long line fishery in Lake Victoria. During the last three to four years, 11 farmers began producing African catfish fingerlings as a major business activity, with an estimated production of 500 000 fingerlings per month. The live fish are packed in jerry cans or buckets and transported in pick-up trucks to fishermen at the lake.

The price of the baitfish (average total length 10 cm) ranges from US$0.06 in the dry season to US$0.17 per fingerling in the wet season. These farmers have constructed hatcheries with all the necessary tanks for induced spawning, stripping, egg incubation, hatching and fry rearing (14–21 days). Fry from the hatcheries are grown in concrete tanks, at densities of up to 2 500/m^3, or plastic lined ponds and raised to baitfish of 10 cm or larger. Cage culture of catfish under commercial conditions is currently being tested by the USAID (United States Agency for International Development)/Uganda Fisheries Investment for Sustainable Harvest (FISH) project.

TABLE 2
Estimated national and regional annual yield and value of major cultured fish species

Region	Species	Fish production (kg/ha/year)	Price (US$/kg) (1999/2000)
Central	Tilapias (*O. niloticus* and T. zilli)	276	1.60
	North African catfish	350	1.10
	Common carp	71	1.10
Eastern	Tilapias (*O. niloticus* and *T. zilli*)	625	1.60
	North African catfish	417	1.60
	Common carp	532	1.50
Northern	Tilapias (*O. niloticus* and *T. zilli*)	588	1.70
	North African catfish	432	1.10
	Common carp	69	1.10
Western	Tilapias (*O. niloticus* and *T. zilli*)	972	1.50
	North African catfish	140	0.90
	Common carp	297	0.80
West Nile	Tilapias (*O. niloticus* and *T. zilli*)	889	1.60
	North African catfish	-	1.65
	Common carp	374	1.60
National Average	Tilapias (*O. niloticus* and *T. zilli*)	646	1.60
	North African catfish	406	1.10
	Common carp	333	1.10

*Price per kg fish is based on the market price not ex-farm gate price, which may be much lower.
US$1.00 = Uganda Shilling (USh) 1 820 (average exchange rate, 2005)

Source: NARO-MAAIF (2002)

In general, there is a lack of accurate production data from small-holder ponds. This is because farmers do not keep records. However, some estimates were obtained by the NARO-MAAIF (2002) baseline survey and these are summarised, on a regional basis, in Table 2. For the most commonly cultured fish species (*O. niloticus, C. gariepinus* and *C. carpio*) the current production level was estimated at 13.8 kg/100 m²/year, which is significantly better than the historical records of 0.7 to 7.1 kg/100 m²/year (Owori-Wadunde, 2001). More recent production data were not available at the time this report was compiled.

2. ANALYSIS OF FERTILIZERS, FEEDS AND FEEDING

2.1 Availability and accessibility of manure and inorganic fertilizers

Fish farming in Uganda mainly consists of mixed species "polyculture" in organically fertilized ponds. This is because the majority of fish farmers are poor, small-holder farmers who keep livestock and grow crops (Isyiagi, 2004). Approximately 58 percent of fish farmers use cattle manure to fertilize their ponds, while others used chicken, goat, pig and duck manure, coupled in most instances (40 percent) with compost cribs that are filled with grass, kitchen wastes and farm by-products such as cabbage stumps. Chicken manure was used least often due to the high price and competition with crop farming (NARO-MAAIF, 2002). Chicken manure is available from commercial poultry farmers at US$16.50 per tonne (Mr. Tugumisisrize, Sunfish Farms Ltd., pers. comm.), which makes it unaffordable for most small-scale farmers. Pig and cattle manure are free. Organic manure is generally applied at approximately 20 kg/100 m². Further application depends on the "greenness" of the pond. Manure is available throughout the year and more than 80 percent of farmers have access to organic fertilizers, although not in sufficient quantities. Most small scale farmers fertilize their ponds using manure swept from livestock enclosures. Approximately 40 percent of the farmers install cribs in their ponds and these are filled with grass, kitchen wastes, animal manure and farm by-products such as cabbage stumps. The rate of refilling the cribs depends on the colour of the water which they monitor visually.

Inorganic fertilizers are rarely used in Ugandan aquaculture. However, there are some farmers who use di-ammonium phosphate (DAP) and nitrogen phosphate potassium (NPK) in catfish nursery ponds. DAP is applied at the same time when the fry are introduced to the nursery ponds. It is dissolved in water and applied at a rate 0.5 kg/100 m². NPK is used at the same rate. Inorganic fertilizers are readily available in agricultural shops. A combination of phosphoric acid and urea has been reported used to sustain plankton growth in ponds (Mr. Tugumisisrize, pers. comm.). The mix consists of 50 l of phosphoric acid and 5 kg of urea, which is applied to 7 000 m² ponds every 2–3 weeks. According to the manager of the farm this treatment results in sustained plankton production, dominated by cladocerans and lesser quantities of rotifers and copepods. In 2005, the price of chemical fertilizers ranged from US$430–500/tonne.

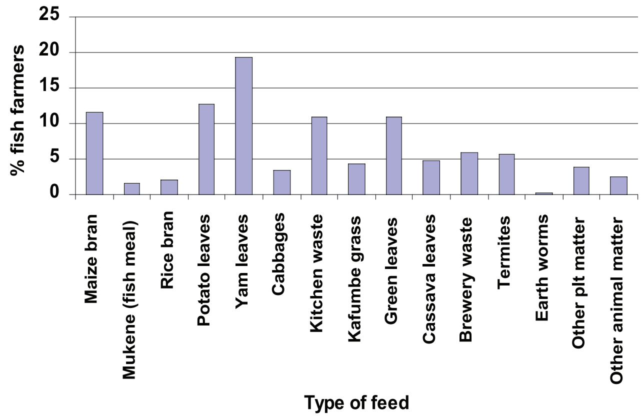
2.2 Availability and accessibility of feed ingredients

A multitude of ingredients are used as fish feeds in Uganda. These include vegetables, grass, cereals, cereal brans, oilseed cakes, industrial and kitchen wastes, insects and fishmeal. The proportional use of these ingredients is illustrated in Figure 1. Availability of most of these feed ingredients is seasonal. Cereals are readily available and cheap at harvest time, but prices gradually increase by the time the next harvest comes around.

Maize

Uganda harvests two maize crops per year with a total production of approximately 500 000–600 000 tonnes (Table 3). For more than a decade Uganda has been exporting 50 000–100 000 tonnes of maize per annum to Kenya through informal trade (Magnay,

FIGURE 1
The proportional use of different types of feeds by Ugandan fish farmers



Source: ARDC, Kajjansi database (pers. comm.)

2004). Relief agencies also purchase approximately 100 000 tonnes per year for the region and Uganda also supplies maize to Tanzania and Rwanda.

The price of maize in Uganda is high and this is because of the substantial volumes that are exported or bought by relief agencies. The average price of maize and maize bran, for the period January to October 2004 was US$0.28/kg and US$0.08/kg, respectively.

Rice

Domestic rice production in 2005 was estimated at 51 917 tonnes (Table 4). This is not adequate to meet the local demand and in 2005 Uganda imported an additional 40 538 tonnes.

TABLE 3
Estimated maize production and trade (tonnes) during 2001–2004

Year	Production (tonnes)	Internal demand	Relief agencies	Export		Surplus
				Formal export	Informal export	
2001	550 000	400 000	50 000	10 000	40 000	50 000
2002	530 000	400 000	50 000	20 000	60 000	0
2003	580 000	400 000	100 000	_	80 000	0
2004 (drought)	530 000	350 000	80 000	20 000	80 000	0
2005 (projections)	600 000	400 000	60 000	30 000	60 000	500 000

Source: Uganda Grain Traders Ltd. (pers. comm.)

TABLE 4
Trends and projections in rice market volumes (tonnes)

	2003	2004	2005	2006	2007	2008	2009	2010
Total rice demand	88 000	90 200	92 455	94 766	97 136	99 564	102 053	104 604
Domestic production	48 000	49 920	51 917	53 993	56 153	58 399	60 735	63 165
Import	40 000	40 280	40 538	40 773	40 982	41 165	41 318	41 440

Source: Spilsbury *et al*. (2004) and author's estimate based on survey findings

The price of rice varies seasonally, ranging from US$0.41–0.44/kg, and is linked to the main harvest times. Rice bran is increasingly used to feed fish and costs less than maize bran.

Kitchen and bakery waste

Kitchen waste is obtained from homes and public eating places such as restaurants, hotels and schools. However, most kitchen waste is collected as pig feed. During the farm visits carried out by the author, it was found that some farmers were feeding fish on waste bread from bakeries in Kampala and in some instances this constituted over 50 percent of the feed. In most instances kitchen and bakery wastes were obtained free as a way of disposal.

Mill sweepings

Farmers in the neighbourhood of feed or flour mills collect the floor sweepings, which they use as feed. Sweepings are of various types, e.g. millet, cassava, sorghum, maize or a combination of all of these. The volume of sweepings produced in the country is not known. Sweepings are obtained free of charge.

Abattoir by-products and waste

Bloodmeal is the principal abattoir by-product and is used for making fish and livestock feed. However, most of the abattoirs are located in urban areas and most farmers are unable to transport the product to their farms. About 400 tonnes of bloodmeal are produced around Kampala. The amount produced in the northern part of Uganda is not known. The price of bloodmeal is US$0.33/kg and no recent changes in volume and price have been reported.

Termites / white ants

According to Isyiagi (2004) some farmers feed their fish on termites, which are either collected by the farmer or purchased from collectors at a cost of US$0.27/kg, during the periods March/April and August/September. The quantity obtained depends on the number and size of anthills on the farm, moonlight intensity and type of white ant. On average, an anthill yields approximately 50 kg per annum.

Oilseed cakes

Cotton and sunflower oilseed cakes are the two major cakes used as fish feed in Uganda. They are purchased from trading centres and major distributors in urban areas. The price of oilseed cakes varies seasonally. Oilseed cakes are used by industrial feed mills as well as small, backyard feed mixers, commonly referred to as *Kitiyo* (literally meaning those who use a spade to mix feeds). Oilseed cakes are not used for human consumption.

Brewers waste

Brewery waste is obtained from local sorghum breweries and from the industrial lager breweries. The wet product (fermented barley and sorghum) is used as a fish and a livestock feed. It was estimated that the two industrial breweries produce around 22 568 tonnes of waste per annum. Brewery waste is sold at US$5.50 per tonne at the factory gate; while the cost to the end user (farmer) is US$11 per tonne. Local brewery waste is available throughout the year.

Green leafy material

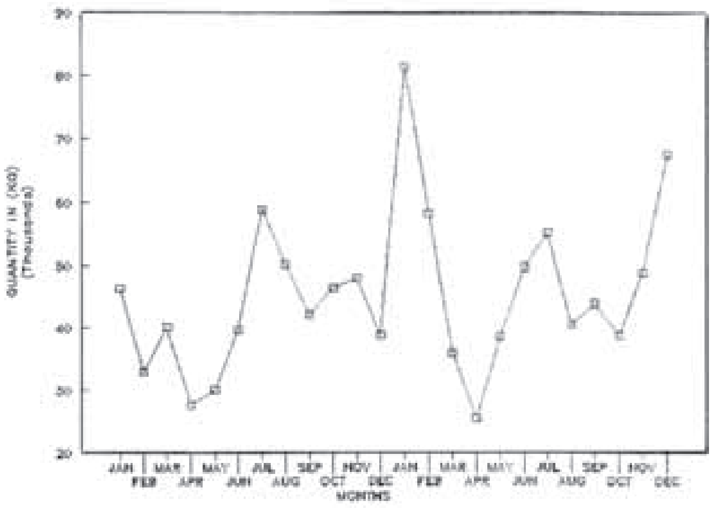
Green leaves are readily available throughout the year in most parts of the country. Nelly (2004) found that farmers use green leaves as a fish feed regardless of whether the fish are herbivorous or not. The most widely used leaves are cocoa-yam, sweet potato, Kafumbe grass (*Galisoga pariflora*) and Kanyebwa grass (*Oxalis latifolia*).

Fishmeal

The pelagic minnow silver cyprinid, mukene or dagaa omena (*Rastrineobola argentea*) is the most important local species for the manufacture of fishmeal, but is also an extremely important source of fish for human consumption. This is similar to the situation in Kenya and Tanzania. Monthly landings of *R. argentea* show two peak periods (Wandera, 1993; Wandera, pers. comm., 2005), December to January and a minor peak in July and August (Figure 2). It is readily available all year around, though prices increase in April and May and in October when catches are low. Catch surveys show that the yearly average catch in Uganda is approximately of 90 372 tonnes. The fish are sun dried and milled and sold at US$0.47 /kg. It is important to note that fishmeal is not imported into the country. Emerging commercial fish farmers use the fish together with other ingredients such as maize, rice bran to produce farm-made feeds. However, the fishmeal is improperly processed and handled. Samples of mukene fishmeal taken at fish markets and discussion with users indicated that it is almost always contaminated with sand. Some of the users believe that sand is added deliberately by the vendors to increase the weight of the fishmeal. To avoid contamination, some of

FIGURE 2

Monthly landings of silver cyprinid *Rastrineobola argentea* at Masese, 1990–1991



Source: Wandera (1993)

the emerging commercial farmers now buy fresh *R. argentea* directly from the fishers, which they then dry on the farm using locally made driers.

Vitamins & minerals

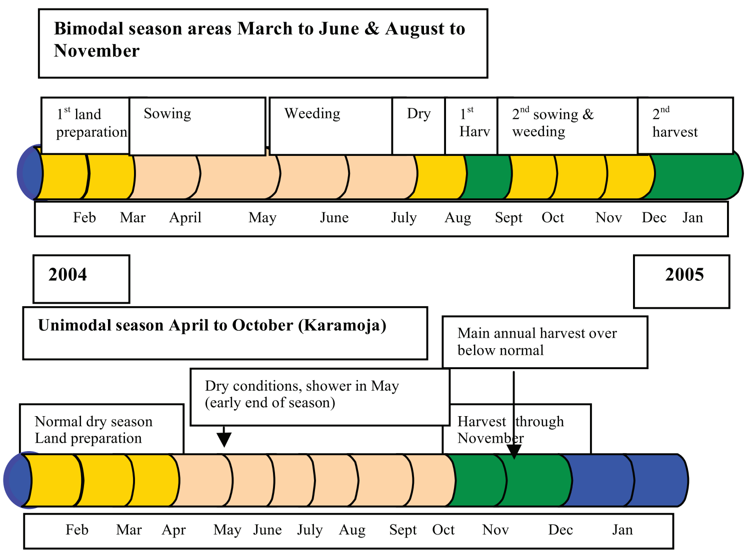
All vitamin and mineral premixes are imported and are readily available in veterinary drug shops throughout the year. The cost ranges from US$17.63–$22.04 per kg. Raw materials for minerals such as cattle horns, fresh water snail shells are readily available in the country and these products cost around US$2.80 per kg.

The agricultural calendar

The agricultural calendar determines the availability and price of commodities. Uganda has two agricultural seasons. One describes the situation in the bi-modal rain areas, while the other focuses on the unimodal rain regions (Figure 3). The main ingredient in animal feeds in Uganda is maize. Quite often there is a scarcity of maize on the market (mainly during the period June to October) due to several factors, including the demand from neighbouring countries and relief needs by WFP, amongst others. This results in large price increases in the informal market (Magnay, 2004) and also leads to seasonal price fluctuations of local animal feeds.

FIGURE 3

Uganda agricultural calendar



Source: FEWS (2004)

2.3 Nutritional composition of feed ingredients

The proximate composition of the available conventional and non-conventional feed ingredients is shown in Table 5. Most of the farm by-products used as fish feed in Uganda have a low protein content. Silkworm pupae have only recently been processed and used for feeding of North African catfish brood stock. According to the farmer the results are encouraging but unfortunately not yet quantified.

2.4 Price, transportation and storage of feed ingredients

The cost of feed ingredients varies with the agricultural calendar and by region. Table 6 shows the range of prices for the commonly used feed ingredients.

TABLE 5
Proximate composition of local feeds and feed ingredients commonly used as aquafeeds (% dry matter)

Feed/ingredients	DE (kcal/g)	DM	CP	CL	Ash	CF	NFE	P	C
Ants/termites	-	-	36.0	1.1	-	-	-	-	-
Barley	3 274	88.0	10.6	2.4	-	4.5	-	0.4	0.1
Blood meal	2 981	87.6	60.5	2.3	25.5	0.0	11.7	0.1	0
Brewers waste	-	-	27.8	12.6	-	-	-	-	-
Broken maize	1 900	85.0	12.0	4.0	-	7.5	-	0.4	0.3
Cassava	3 188	88.0	2.5	-	-	4.5	-	0.1	0.2
Cassava leaves	-	-	25.8	15.2	-	-	-	-	-
Coco-yam leaves	-	-	19.5	17.8	-	-	-	-	-
Cotton seed cake	2 422	94.0	41.1	6.2	7.9	6.2	38.0	0.5	0.1
Cotton seed oil	9 000	68.6	-	99.5	-	-	-	-	-
Fishmeal (*Alectes jacksoni*)	3 400	90.0	62.0	8.2	-	0	-	3.0	4.9
Fishmeal (gomba)	2 800	90.0	39.0	15.0	-	0	-	4.0	7.0
Fishmeal (*R. argentea*)	3 402	93.1	60.9	10.3	-	0	-	2.3	2.5
Kafumbe grass (*Galisoga pariflora*)	-	-	22.4	14.9	-	-	-	-	-
Maize	3 593	85.0	8.8	3.9	-	2.1	-	0.4	0.3
Maize bran	-	87.2	6.9	5.8	1.6	7.5	85.7	0.4	0.02
Cane molasses	1 800	-	4.0	-	-	-	-	0.1	0.7
Rice bran	-	-	10.1	18.3	-	-	-	-	-
Rice hull	1 950	89.9	7.0	1.0	-	20.0	-	0.5	0.03
Sesame cake	3 337	89.5	38.5	9.0	-	4.0	-	0.9	1.7
Silkworm pupae meal	-	-	52.1	15.5	7.2	2.9	22.1	-	-
Soy cake, pressed	2 900	87.0	43.0	1.8	-	6.5	-	0.7	0.3
Soybean, whole	4 241	90.0	36.0	18.8	-	5.8	-	0.5	0.2
Sunflower cake, pressed	2 086	88.0	25.0	10.2	-	22.0	-	1.0	0.3
Sunflower oil cake	-	94.8	41.7	12.9	4.6	16.5	30.8	4.6	0.2
Sweet potato	3 440	87.5	3.8	0.7	-	2.7	-	0.2	0.1
Sweet potato leaves	-	-	20.4	15.9	-	-	-	-	-
Wheat bran	-	79.6	14.6	-	-	10.5	-	-	0.1
Wheat flour	3 441	88.0	12.0	2.0	-	2.0		0.4	0.3
Wheat pollard	1 450	90.0	13.0	4.0	-	7.0		0.4	0.1

DE= digestible energy, DM= dry matter, CP = crude protein, CL = crude lipid, NFE = nitrogen free extracts, P = phosphorus, C= calcium

Source: Apolot (2003); Isyiagi (2004)

At the peak of the harvest season commodity prices tend to be lower and then increase with demand and decreasing supply. The cost of fishmeal also fluctuates seasonally. It is lower during January and February and higher from March to May (Table 6) due to lower catches during this time of the year.

TABLE 6
Production and price of various feed ingredients

Ingredients	Annual production (tonnes)	Annual price range (US$ per kg)		
		Mean	Minimum	Maximum
Sesame seed cake	1 000	0.14	0.11	0.19
Cotton seed cake	12 000	0.14	0.08	0.17
Sunflower cake	5 000	0.11	0.10	0.14
Groundnut cake		-	-	-
Maize bran	-	0.080	0.07	0.09
Fishmeal	-	0.385	0.1	0.67
Cotton seed cake	-	0.017	0.014	0.02
Shells (mineral)	-	0.090	0.09	0.09
Vitamin premix	-	5.560	5.56	5.56
Soybean cake	-	0.500	0.44	0.56
Blood meal*	400	0.420	0.42	0.42
Snail shell	-	0.095	0.08	0.11
Bone meal	-	0.190	0.19	0.19

* This figure is for the Kampala district

Source: Mutima Best Quality feed dealers, Kisenyi, Kampala (pers. comm.)

Transportation of feeds and feed ingredients takes various forms including carrying the sacks on people's head, bicycles and trucks. Some villages or trading centres have mills where cereals are processed for food, leaving behind bran which is used to feed livestock and fish. Bran from the

FIGURE 4
Loading and off loading of feeds and feed ingredients from and to trucks ready for transportation

mills in urban centres is packed in 100 kg bags and transported by traders from all over the country in trucks while loading and offloading the trucks is done by hired labourers (Figure 4). The cost of transportation is US$1.11 km/tonne.

In the past rural people in Uganda stored and preserved food in traditional granaries. Cereals or dried cassava were kept in such granaries for years without loss. Unfortunately this practice is disappearing. Farmers now sell their produce immediately after harvest and store very little of it for later use. This practice is based on the need for school fees and other requirements and a false sense of security that food can always be bought. The country does not have silos or other facilities for storing enough food for the population for any length of time. Fortunately, Uganda is blessed with two rainy seasons; hence prolonged dry seasons are uncommon.

The lack of adequate storage facilities is a major constraint to growth of the aquaculture sector in rural areas, because farmers cannot purchase ingredients when prices are low and store them for use later in the year. With the emergence of commercial fish farming it is hoped that farmers will construct proper feed stores. This initiative is being spearheaded by the FISH project, which has already selected model farmers on condition that they have or will construct feed stores.

2.5 Feed formulation and manufacturing

Feed formulation depends entirely on the availability of ingredients and their cost. Commercial fish farmers combine feedstuffs in various ways. For example, some emerging commercial fish farmers mix 70 percent maize bran and 30 percent fishmeal or sunflower or cotton oilseed cake. The ingredients are pounded or milled, mixed at the required proportions (when adequate quantities are available) and broadcast over the surface of the pond. Some farmers moisten the mixture to minimise loss by wind dispersal, while others mix the feed ingredients and cook the mixture to make a cake. In other instances, hot water is added to the formulated mixture and kneaded into dough that is passed through a meat mincer to make “spaghetti” (Figure 5a). The “spaghetti” is dried on corrugated iron or plastic sheets (Figure 5b) or in solar driers (Figure 5c & d). For fish fry the dried “spaghetti” is blended and sieved using mesh sizes of 200 µm and 350 µm. The pellets tend to remain stable in water for some time and hence loss into the pond bottom is minimized. Commercial catfish hatchery owners formulate a starter diet consisting of 5 kg of fishmeal, 3 kg of whole soybean flour and 2 kg of whole

FIGURE 5
Feed processing and drying (a) feed pelleter (b) direct sun drying on corrugated iron sheet (c) solar dryer (d) improved solar dryer

COURTESY OF J. RUTAISIRE AND OWORI-WADUNDE maize flour and five eggs. However, Aquafarm and Umoja farmers follow the recipe recommended by Hecht, Uys and Britz (1988) (visit www.ru.ac.za/academic/departments/difs for further details).

Only one company in Uganda produces a sinking pellet. The process involves milling the ingredients, formulating, mixing and steam pelleting (77°C) and fat injection, cooling (25°C) and bagging. The pellets are produced in two sizes, 2 mm and 3 mm and have a water stability of around 45 seconds. The installed production capacity for pellet production is five tonnes per hour but only a few tonnes are produced upon request. This is mainly due to a lack of demand and the hesitancy by the producer to store feeds. The company is now cooperating with the FISH project to produce an extruded diet.

FIGURE 6
Pond attendant feeding cat fish fry reared in a plastic lined nursery pond

2.6 Feeding practices

The main herbivorous fish produced by small-scale, subsistence farmers is *Tilapia zillii* and it is mainly fed on coco yam and potato leaves or on Kafumbe grass (*G. pariflora*) and Kanyebwa grass (*O. latifolia*). Most green vegetable feeds are either chopped or presented whole to the fish. There is on-going research to determine optimum conditions for polyculture of *T. zillii* with *C. gariepinus*. Most small-scale farmers do not feed their fish at regular intervals but do so depending on availability of material and when they have time. According to Nelly (2004), 22 percent of small-scale farmers do not feed their fish at all, 46 percent feed daily, 10 percent feed once a week, 9 percent feed several times a week, 4 percent feed fortnightly and 9 percent feed their fish irregularly. The leaves are tied together and simply thrown into the pond. The fish eat off the leaves leaving the stalks, which are removed by the farmer.

The major commercial aquaculture species are *O. niloticus* and *C. gariepinus* and the main feeds for these species are maize bran, cotton and sunflower oilseed cake and fishmeal. Commercial farmers feed their fish with pellets, steamed oilseed cake or dry mash. Pellets and powder/mash are broadcast over the pond or tank surface regardless of the species or culture system (Figure 6), whilst the steamed oilseed cakes are presented on feeding trays. There is no information on FCRs of the farm-made feeds.

On commercial farms, fry are fed at 15 percent of body weight per day, decreasing to 6 percent and below towards the end of the culture cycle. Feeding frequencies vary between farmers and by region, but normally fish are fed twice daily. The major problem is that most farmers do not know the biomass of fish in the ponds and cannot therefore determine appropriate rations.

Despite the recent advances, the development of aquaculture in Uganda is constrained by the absence of good commercial feeds and a lack of technical know-how to make appropriate farm-made feeds. Emerging commercial fish farmers have therefore had no option but to haphazardly formulate feeds on their farms. During 2005, a number of commercial fish farmers resorted to importing feed from a South African company (Aquanutro (Pty) Ltd.), for catfish fingerlings. Other foreign feed companies are now also showing interest in supplying catfish producers with formulated feeds.

2.7 Labour costs

Labour is available in most parts of the country, though it is largely unskilled. Labour costs are highly variable (most expensive in urban areas and cheapest in rural areas). The cost of hiring unskilled labour in Kampala is US$2.70 per day, but decreases with distance from the city.

3. THE ANIMAL FEED INDUSTRY IN UGANDA

As mentioned previously, there are no industrial aquafeed manufacturers in Uganda. What is presented below pertains to the general animal feed industry, which started in the late 1960s. The earliest feed company was registered in 1967. Currently there are about 28 industrial and small-scale feed manufacturers in Uganda. Currently, some 80 000 tonnes of animal feeds are produced by all large and small-scale mills (*Kitiyo*), of which 85 percent (68 000 tonnes) comprises poultry feed. The small mixers account for 60 percent of the production. However, inadequate services (delivery, quantity and quality) have had their toll on the development of the livestock feed industry. The availability of good quality animal feeds at affordable prices can only be improved by creating an enabling environment for private sector investment. A national feeds policy to guide the industry was drafted in 2000 but has yet to be approved by the Parliament. The objective of the animal feeds policy is to maximise the potential of Uganda's livestock resources on a sustainable basis within the context of sound environment management (MAAIF, 2000). The policy emphasises increased production, supply and availability of good quality feeds for all categories of livestock at the lowest cost. The following articles of the draft policy are particularly noteworthy:

- **Article 3** provides guidelines on importation, manufacture and sale of animal feeds and feed ingredients.
- **Article 4** calls upon all persons, firms, corporations etc. engaged in the production, selling or distribution of animal feeds to indicate on the package a written statement containing the following: name and address of manufacturer, brand name, net weight, description and percent of each ingredient in the feed, the species and the type of animal for which the feed is intended, date of manufacture and expiry and the recommended conditions for handling, storage and use.
- **Article 5** specifies quality control services; this article puts in place mechanisms of maintaining and controlling animal feed quality.
- **Article 6** deals with adulterated feed/feedstuffs; in this article guidelines for storage and transportation of feed and feedstuff and the penalties, which include fines and maximum jail terms are stipulated.

Catfish hatchery operators are hardest hit by the absence of affordable manufactured commercial feeds and as mentioned above have resorted to importing starter diets. The FISH project also initially imported 16 tonnes of fish feed from a USA based feed company (ZEIGLER BROS., INC.), during December 2005. By using the imported feeds farmers have demonstrated the value of well balanced feeds and this may motivate local entrepreneurs to invest in an appropriate aqua-feedmill. According to a private commercial fish farm (Sunfish Farms Ltd.), which imported feeds from South Africa in November 2005, feeds are charged with a holding tax of 6 percent, value added tax at 18 percent and import duty of 10 percent. There is no information with regard to taxes on locally manufactured feeds. Farmers have made a request to government to waiver the import duty on aquafeeds, while the governments' stand, on the other hand, is to waiver taxes and duty on feed manufacturing machinery so as to encourage local manufacturing. Clearly there is a need for more dialogue to resolve these issues such that a win-win situation is created.

4. PROBLEMS AND CONSTRAINTS

- The lack of an affordable industrially manufactured pelleted feed remains one of the major constraints to the development of aquaculture in Uganda. The manufactures are unsure of a sufficient and sustained demand to warrant the high investment costs. On the other hand, many fish farmers claim that they cannot expand their business without high quality manufactured feeds.
- Farmers are unaware of the opportunities offered by farm-made feeds.
- There are many locally available ingredients that can be incorporated in fish feeds.

However, supply and price fluctuations can be crippling. Hence there is a need for farmers to invest in storage facilities, which will allow them to purchase adequate quantities of ingredients when prices are favourable.

- Poor processing, handling and storage affects the quality (mould, high sand content, mixed ingredients) of many raw material, such as fishmeal, rice bran and others. This in turn affects the quality of farm-made feeds.
- Accessibility to feed ingredients is constrained by poor infrastructure (roads, storage facilities) in remote parts of the country where feed crops are produced as well as by the high transport and fuel costs (US$1.00 and 1.22 per litre of petrol and diesel, respectively).
- Most fish farmers are poor and cannot afford to buy and store feed ingredients for sustainable on-farm feed processing and hence only purchase small quantities at high retail prices for immediate use. This reduces their profit margins and in some instances aquaculture becomes uneconomical. It is very difficult to make reasonable suggestions on how such farmers might escape the poverty trap, except that the state should provide adequate infrastructure and invest more heavily in education and health services in rural areas.
- Preparation of farm-made feeds is constrained by a lack of electricity and machinery on most fish farms in the country. Some fish farmers use hand operated mincers to make feeds, but this restricts the size of the fish farming operation. Unfortunately only a handful of farms are on the national power grid and farmers that use generators are constrained by the high fuel cost.
- The method of broadcasting milled feeds on the water surface is wasteful. This calls for improved skills and knowledge transfer.
- There is a paucity of data on the current use of feed ingredients as most farmers do not keep records. It is therefore difficult to determine the total cost of inputs (including feeds) and outputs, hence important indices such the feed conversion ratios cannot be determined.
- Inorganic fertilizers are readily available in Uganda. However, the high unit cost is a major constraint. Organic fertilizer (manure) is available all year round though farmers often cannot source, purchase and or store adequate quantities.

5. RESOURCE AVAILABILITY AND EXPANSION OF AQUACULTURE

Uganda is endowed with a wide variety of aquatic and agricultural resources that can support rapid growth of the aquaculture sector. Nearly 18 percent of Uganda's total surface area is covered by rivers and lakes and wetlands and rainfall ranges between 600–2 500 mm per annum. The water and soil resources offer great opportunity for land and water based aquaculture. This, coupled with the widening gap between fish demand and supply in Uganda, and in the region as a whole, and the over fished (and or destroyed) natural fish stocks provides the impetus for investment in and expansion of aquaculture.

Successful aquaculture industries are often and usually preceded by a successful fishing industry, which establishes fishery products, markets and infrastructure for processing and distribution. The established markets for Nile perch and other indigenous fish species coupled with the established processing, transport and other infrastructure, entrepreneurial interest and supportive economic policy will synergistically work to promote aquaculture development in Uganda.

6. RECOMMENDATIONS FOR THE IMPROVED UTILIZATION OF FERTILIZER AND FEED RESOURCES

1. Suitable feed ingredients from different agro-ecological zones must be identified and analysed and an aquafeeds database must be developed for each agro-ecological zone.

2. The soils of the various agro-ecological zones must be analyzed to determine nutrients that are likely to be limiting and these data must be used to develop a country profile for aquaculture development and investment.
3. Farmers must be trained in the use of fertilizers, handling, application and monitoring of fish production.
4. Fish farmers must be trained to keep records to estimate production and profitability. There is a need for a comprehensive programme to generate vital statistics to serve as benchmarks for aquaculture investment in the industry. Currently it is not clear what it takes to produce a kilogramme of tilapia or any fish species cultured in Uganda.
5. An inventory of fish farmers in the country must be established and maintained to estimate their potential, full production capacity and feed requirements.
6. Guidelines for farm-made feed formulation, processing, handling, storage and application and optimal fertilizer use must be developed.
7. The production and processing of soybeans must be promoted as an alternative to fishmeal. This is of particular importance because of the demand for *R. argentea* as food.
8. There is a need to revive and modernise traditional granaries for effective feed storage.

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APPENDIX

APPENDIX A: Feed formulation for North African catfish

A.1. Recommended formulation of a dry feed for *Clarias gariepinus* larvae and early juveniles, procedure to manufacture feed and its application

Ingredients	Composition (% as fed basis)
Torula yeast (*Candida utilis*)	50
Fishmeal	43
Vitamin and mineral premix	1
Fish oil	3
Sunflower oil	3
Total	100

Procedure:

1. Mix yeast and fishmeal with water to produce dough.
2. Roll dough out into thin cakes and dry at 45°C in oven.
3. Grind the dry cakes and sieve into particles of size ranges 125–200 µm and 200–350 µm.
4. On a daily basis, mix the proportional amount of oil and vitamins with an appropriate amount of stock mixture.
5. Discard what is not used within 24 hours.

Application:

Use fine particles (125–200 µm) for the first four days and large particles (200–350 µm) on subsequent days. Apply at least 20 g per 500 litre container every 2 hours, day and night, and in any case, not less than 40% of body weight per day.

Source: www.ru.ac.za/academic/departments/difs (and see CD ROM Resources)

APPENDIX B: Agricultural calendar

B.1. Agricultural calendar for selected crops with potential for inclusion into fish feeds

Crops	Month	Zone/regions			
		Northern	Eastern	Western	Central
Cotton	May-June	Planting	Planting	-	-
	June-July	-	-	Planting	Planting
	October	Harvesting	Harvesting	-	-
Maize	November	-	-	Harvesting	Harvesting
	February		Planting starts	Planting starts	Planting starts
	March	Planting starts	Planting continues	Planting continues	Planting continues
	April	Planting continues	Planting continues	Planting continues	Planting continues
	May	-	-	Planting continues	-
	June	Harvesting green maize	Harvesting green maize	Harvesting green maize	Harvesting green maize
	July-August	Harvest, dry	Harvesting in high altitude areas starts	Continue harvesting	Complete harvesting & plants for second rains in August
	September	Plant in wetter areas ends mid month	Harvesting & planting in highlands & ends same month.	Complete harvesting & plants for second rains & ends same month.	End of planting
	October	Start harvesting	-	-	-
	November	Harvesting	Harvesting	Harvesting	Start harvesting
	December	End of harvesting	End of harvesting	End of harvesting	End of harvesting
Cassava/sweet potatoes (leaves)	February	Start planting in wetter areas	Details of the crop calendar are same as in the northern region.	-	Details of the crop calendar are same as in the northern region.
	March-May	Planting continues & ends in May		Planting starts in March & ends in April	
	May–July	Harvesting starts in May & harvesting is completed in July		Partial harvesting start in June and harvesting is completed in July	
	August–October	Plating 2nd rains start & ends in October		Plating 2nd rains start & ends in October	
	December–February	Starts harvesting & ends in February following year	-	Starts harvesting & ends in February following year	-

B.1. Continued

Crops	Month	Zone/regions			
		Northern	Eastern	Western	Central
Beans/ soybeans	January- May	Planting start mid March or end month & ends in April	Planting start in February & end in March. Green harvest start in April	Planting start mid March in dry areas & end in May.	Early planting start January & ends in March, Green harvest in April
	June-August	Green harvest start in June	Harvesting continues & harvest completed in July.	Green harvest starts in June & completed in August.	Harvesting continues & harvest completed in July.
	August–October	Harvesting continue & harvest completed in October	Planting for 2nd rains & ends in mid September	Planting for 2nd rains & in October in drier areas	Planting for 2nd rains in September
	November–December	No activities	Start green harvesting & complete harvesting in December	Start green harvesting	Start green harvesting in November & complete harvesting in December.
	January following year	No activities	-	Complete harvesting	-
Vegetables (leaves)	January-March	Harvest & bed preparation, Sow nursery beds & begin transplant in March	Sow nursery beds & harvest in valley swamps, transplanting starts & main transplanting in March	Maintain nursery swamp crops, sow nursery, prepare field in February & transplant in March	Maintain nursery swamp crops, sow nursery, prepare field in February & transplant in February & continue sowing and transplanting in March
	April-May	Transplant, maintain old gardens, harvest up to June.	Transplant continued, hardening of seedling for may transplant, start regular harvesting in May, complete 1st rains planting except near valleys & continues regular harvesting.	Transplant up to June, Harvest earlier crops, sow nursery beds & plant swamp crops	Continue sow, transplant up to may, harvesting continue up to June
	June-September	Maintain fields & nursery beds, harvest, sow nursery beds	End of 1st rains planting in June except in valleys/ swamps, harvesting, sow new nurseries in July & start transplanting in August.	Sow nursery beds & plant swamp crops in June, harvest and prepare fields in July, maintain swamp crops, prepare new fields for nurseries, maintain old fields & harvest. Harden seedlings in September for October planting	Continue harvesting in June, maintain swamp crops, prepare new fields for nurseries, sow nurseries up to August & transplant in September
	October-December	Prepare valley swamps fringes, harvest old fields, plant out in swamps in December	Continues planting & sow nursery beds for valley and swamp fringes harvest up to December, land preparation and sowing beds in December.	Continue planting (valley/ swamps), Start harvest in November and Open nursery beds in December.	Continue planting, start harvesting in October up to December, Preparation of new fields and nurseries in December.

WORKSHOP REPORT

Report of the FAO Expert Workshop on "Use of feeds and fertilizers for sustainable aquaculture development"

WUXI, JIANGSU PROVINCE, PEOPLE'S REPUBLIC OF CHINA, 18–21 MARCH 2006

ORGANIZED IN COLLABORATION WITH THE FRESHWATER FISHERIES RESEARCH CENTRE, WUXI, CHINA AND THE NETWORK OF AQUACULTURE CENTRES IN ASIA-PACIFIC (NACA)

THE WORKSHOP

The Aquaculture Management and Conservation Service (FIMA) of FAO organized an expert workshop on the "Use of feed and fertilizer for sustainable aquaculture development" in Wuxi, Jiangsu Province, People's Republic of China, on 18–21 March 2006 in collaboration with the Freshwater Fisheries Research Centre (FFRC) of China and the Network of Aquaculture Centres in Asia-Pacific (NACA). The workshop was hosted by Freshwater Fisheries Centre (FFRC), Chinese Academy of Science at the FFRC Campus in Wuxi, Jiangsu Province, China. The workshop was undertaken as a part of FIMA's work programme entitled "Study and analysis of feed and nutrients (including fertilizers) for sustainable aquaculture development" under the programme entity "Monitoring, Management and Conservation of Resources for Aquaculture Development".

OBJECTIVES AND OUTPUTS OF THE WORKSHOP

The principal objective of the workshop was to review and analyse the current status and trends in aquaculture production and to identify key issues and challenges of feed and fertilizer resource use for sustainable aquaculture development. Several key issues were identified and prioritized during the technical and working group sessions and appropriate actions were recommended.

The anticipated outputs were to publish the proceedings of the workshop and to provide recommendations to the Third Session of the COFI Sub-committee on Aquaculture (SCA) that was held in New Delhi, India, September 2006. The identified key issues and recommendations made to the third session of COFI-SCA (i.e., policy guidelines, research, capacity building, extension and application) are expected to enable policy makers on a global and regional level to implement improved aquaculture practices and farming systems through optimal use of feeds and fertilizers resources and to assist FAO member countries in the implementation and promotion of the provisions of the Code of Conduct for Responsible Fisheries (CCRF Article 9.4.3[1]).

PARTICIPANTS

The workshop was attended by a wide range of research and development and industrial experts in aquaculture nutrition from around the globe (Annex V).

OPENING OF THE WORKSHOP

The participants were welcomed by Prof Xu Pao, Director, Freshwater Fisheries Research Center (FFRC), Chinese Academy of Fishery Sciences and the workshop was opened by Mr Li Jieren, Vice President of the Chinese Academy of Fishery Sciences.

FORMAT OF THE WORKSHOP

The workshop included technical presentations and working group discussions. The technical presentations were intended to orient the participants to the inter-regional commonalities, differences and problem issues pertaining to the use of feeds and fertilizers in aquaculture. The technical presentations included:

- Country Reviews: Study and analysis of feeds and fertilizers for sustainable aquaculture development
  - China, India, the Philippines, Thailand, Viet Nam, Egypt and Uganda
- Country Reviews: Development of aquafeed industries
  - China, India and Egypt
- Regional Syntheses
  - Feeds and sustainability of Asian aquaculture
  - Developments in sub-Saharan African aquaculture: feeds and fertilisers
  - Aquaculture feeds in Latin America: a look at key elements at the macro (the industry) and micro (farm practices) levels
- Presentation of case studies on economics of aquaculture feeding practices
  - Case study on the use of farm-made feeds versus commercially-formulated pellets for pangasiid catfish in the Mekong delta, Viet Nam
  - The economics of small-scale aquaculture feeding systems in China
  - An economic analysis of aquaculture feeding systems: a synthesis of three Asian countries
- Invited presentation
  - Reducing waste production of aquaculture by improvement of feed formulation and feeding regime
- Global Synthesis
  - Feeds and nutrients for sustainable aquaculture development within developing countries: a global synthesis

Participants were then divided into two working groups and tasked to examine one or more thematic area(s) on feed and fertilizer use in aquaculture, to identify critical issues and to suggest specific actions and make recommendations to address these issues (the working group procedure is detailed in Annex IV). The working group recommendations were presented to the plenary for approval.

[3] CCRF Article 9.4.3: States should promote efforts which improve selection and use of appropriate feeds, feed additives and fertilizers, including manures.

SUMMARY OF WORKING GROUP OUTPUTS: IDENTIFICATION OF KEY ISSUES AND RECOMMENDATIONS

WORKING GROUP A THEME: Industrial aquafeed- development of the industry, impact of availability of protein sources, alternatives and their feasibility

The working group recognized that commercial feed production was generally driven by market forces and this has a strong influence on the decisions made by aquafeed producers. However, there are a number of areas where external forces have an influence on the feed sector or where the feed sector relies on external support/advice or resources. The group also affirmed that the real price of fish was not increasing. This means that feed utilization must become more efficient and, wherever possible, cheaper feeds will have to be produced. The working group identified five areas that require attention and remediation to ensure the sustainable development of the sector. These are:

- Policy and regulation
- Ensuring that research is effectively connected to commercial reality
- Capacity building and management, particularly at farm level
- Fish-based ingredients and alternatives
- Availability and sourcing of ingredients

1. Policy and regulation

Legislating on feeds may not be an effective way to regulate resource use as overly high restrictions can increase the price of feed to a point where farmers may have difficulty in making a profit. There are three levels at which it is possible to influence the sector.

- Government legislation regarding allowable environmental impacts and food safety requirements of the product
- The market determines the demand and price of the product and this influences the activity and decisions of the farmer.
- Greater awareness of farmers regarding optimal production methods and management

1.1 Setting national feed standards

In several countries, national standards have been set for the nutrient content of feeds for a number of species. However, this does not deal adequately with the diversity of production systems. While it is relatively easy to define standards for cold, clear water systems it is more complex in warm, greenwater systems in which the fish obtain considerable supplemental feeding.

The setting of standards for feeds that have overly high nutrient levels (such that they reflect the complete requirement of the animal) may actually encourage inefficient resource use and also limits the ability to capture the benefit of supplementary nutrition in the pond/production environment.

Any standards should reflect the reality of farming systems and the natural variability that exists between these systems. National standards can be misleading since they may be benchmarked against fishmeal based feeds. Standards should be more flexible to indicate a range (protein, CHO, energy etc.) for different farming systems rather than an absolute figure based on the nutritional requirements of species. Hence, there is a need to review national standards and develop realistic guidelines or advisory material regarding the likely needs for different systems and species. This should be used to inform national aquafeed legislation

1.2 Lack of quality standards for raw materials
There is a need to review nutrient specifications of raw materials and to set classification standards for raw materials (i.e. a classification system Class A, Class B etc.), that could then be used for different feeds and culture systems. This would greatly assist feed manufacturers.

Example
Different types of lecithin quality in China

1.3 Review existing mechanisms of incentives and subsidies in the animal feed sector
The range of incentives and subsidies are vast and could not be dealt with in the allotted time. Nevertheless it was recognised that incentives can play an important role in enabling or constraining parts of the aquaculture sector and which may preferentially favour export orientated aquaculture over smaller scale domestic activities.

Examples
- Reduced duty on feed and or raw material imports or duty free imports
- Tax exemptions on feeds for products destined for export
- Feeds classified as 'foodstuffs' may be subject to high tariffs
- Import substitution should be eligible for reduced duties
- Zero tax on major feed ingredients
- High import tariffs on feed additives/pre-mix (leads to smuggling and associated problems with regard to labelling and inclusion of banned substances)
- Government incentives for R&D leading to a reduction in inclusion levels of critical raw materials or their replacement

1.4 Impose levies on feeds and direct the proceeds into research and development
While the direct benefits of a levy are clear and very sensible, this is typically unpopular with the industry since the cost of the levy is inevitably transferred to the farmer. The imposition of feed levies to fund R&D requires clear demonstration that the public sector will use the research funds appropriately and that the research will be useful for all sectors of the industry. In addition there would have to be a strong partnership between research and the industry to set research priorities. Such a fund could also be used for training to improve feed utilization at the farm level.

1.5 Provision of affordable credit to break the barrier for extensive farmer to go into semi-intensive operations
This is of particular importance in Africa but examples from other regions also exist. There is a strong need to inform financial institutions of the economic benefits of aquaculture, the need to feed fish and its impact on the ability to repay a loan

Example
- In Africa, lack of land tenure prevents the use of land as collateral and constrains borrowing.
- Philippines – government bank provides loans to small producers wanting to move to semi-intensive operations, but they have to from fishery cooperatives to access (no collateral) loans.

1.6 Environmental regulations to be developed to limit impacts of aquaculture
Feed mills need to improve feed quality to reduce leaching of nutrients and to improve digestibility of the feeds.

Example

– China is considering a ban on the use of trash fish in the near future
– China is also considering discharge regulations

2. Ensuring that research is effectively connected to commercial reality

Laboratory based feed research relies on controlled conditions. In most instances laboratory trials cannot continue until the fish has reached market size and thus may have limited application to commercial culture conditions. Many feed companies undertake their own research under commercial farming conditions to fully test their feeds; however this information is often proprietary and is not generally available.

There is a need to partner public funded research with the commercial feed manufacturing sector. This will provide a better understanding of reality. It will also allow the setting of better standards and will allow research results to be more effectively transferred to farmers.

Example

Clearwater nutrition trials on tilapia nutrition do not allow for the contribution of phytoplankton to nutrition. If tilapia are well fed they will not use the phytoplankton as a supplement, thus a balance in the diet and feeding regime needs to be reached to optimize the systems.

2.1 Increase dialogue between the feed industry, academia and farmers and encourage cooperative research

It is of critical importance that industry and research organizations are effectively linked. In many countries research is often solely focussed on high value species and export oriented production/producers. Governments have an obligation to ensure that attention is also paid to the domestic sector and lower value crops.

Example

– China - feed industry has regular meetings with academics and fish farmers.
– Strong dialogue between Norwegian salmon farms and government with respect to management and research
– Brazil shrimp farmers association – development of industry GMP's, biosecurity protocols of disease emergence and water quality standards and consistent ingredient labelling
– Thailand – farmers association (annual meeting between farmers and scientists)

2.2 Determine proper feeding regimes and develop aquafeeds for specific culture systems

Feeding regimes should reflect the purpose and goal of the producer. Feeds for herbivorous/omnivorous species may not adequately incorporate the contribution of nutrition from the pond environment.

Example

Export quality tilapia may require that complete feeds and clearwater systems are used, whereas a domestic market may produce fish in greenwater systems with a cheaper feed to reduce production costs.

2.3 A general lack of baseline information on the nutrient requirements of most species in developing countries

There is a real need to assess and better understand the nutritional requirements of fish in marine as well as freshwater, greenwater / heterotrophic systems over and above that which they obtain from supplemental pond nutrients. Of critical importance for the farmer is that this type of research be conducted on a commercial scale, over the entire production cycle, and that it incorporates an economic analysis.

3. Capacity building and management

3.1 Capacity building at farmer level

It must be recognized that the majority of aquafarmers operate at the household level and have relatively limited education. This means that the transfer of complex technical messages is problematic and requires continuous attention

3.2 Facilitate establishment of fish farmer associations to exchange information and facilitate education

This often enables farmers to access information more effectively.

3.3 Clustering of fish farms (small farms) to reduce risk

Large operations have a higher degree of control over inputs. However, smaller operations lack critical mass to exercise any degree of control over input costs and this increases risk. Risk can be reduced if farms are clustered or if farmers organize themselves into groups.

3.4 Training and extension services for small scale farmers must be enhanced

Government support for farmer training is inclined to favour those producing high value or export commodities. There is a need for better extension into domestic systems. Farmers associations can access information easier than individual farmer and can also train their members.

3.5 Capacity building results in significant increases in feed utilization efficiency

There is a need to disseminate information to farmers on more efficient farm management practises and efficient use of feeds (e.g., monitoring, feed trays etc.). The industry is developing rapidly and farmers must keep pace with new technologies and developments, which otherwise will lead to greater inefficiencies.

4. Fish-based ingredients and alternatives

4.1 Fishmeal replacement

Fishmeal can be replaced to a large extent but at a cost (e.g. enzyme and amino acid supplementation), which brings the final cost of alternative feeds in line with fishmeal based diets. At this stage fishmeal is still relatively available and practices will continue until such time as the availability of fishmeal becomes seriously constrained.

4.2 Alternatives for fishmeal and fish oil

There is a pressing need to look at the use of unconventional feed ingredients, but there is limited knowledge or information on possible alternatives and their availability. Fish oil is considered to be a serious limiting factor; however there are alternatives that have not been fully explored. There is a need to look more closely at these alternatives and address the issues that relate to the constraints to their use (e.g. anti-nutritional factors).

4.3 Encouraging the move away from the use of trash fish

There is increasing consumer pressure for aquaculture to become more responsible and for the sector to use more sustainable resources as fish feed.

Example

China has taken note of the pressure and is considering a ban on trash fish use in the future. Moreover, the use of trash fish in the pangasid catfish industry raises potential future problems with respect to water quality and disease.

4.4 Research on fishmeal and fish oil replacements
Research is ongoing but the findings have not been translated into commercial practice.

Production and use of silage and/or fish hydrolysates using low value/trash fish or fish processing wastes
Fish silage and hydrolysates can substitute fishmeal to a certain extent and also act as effective attractants. These products are available but because they are wet it raises problems for large scale feed manufacturers. The technology for the manufacture of silage and hydrolysates is available but not yet transferred and/or the products are still expensive. These commodities provide options and opportunities for farm-made feeds and or small scale producers of moist feeds.

Improve fishmeal quality
There is a need for a greater degree of engagement with local fishmeal producing plants to improve the quality of their product or production efficiency. The down side of improving fishmeal quality is that the price will increase, which may have serious financial repercussions for small scale farmers.

Reducing the dependence on fishmeal imports
It was generally agreed that there has not been much focus on alternatives since fishmeal up to now has been readily available. However, the situation is changing and countries need to consider ways and means to reduce the dependence on imported fishmeal. India has largely succeeded in this endeavour, despite the fact that the local fishmeal is not of the same quality as that which is imported.

Examples
- Some countries regulate import of feedstuffs to protect the national market
- Classification of ingredients as feed grade/food grade
- Specific tariffs on additives
- Rising fishmeal prices does not seriously impact on the economics of farms that produce high value products. However, rising process seriously affects the profitability of lower value species farms.
- Governments can and should play an active role in encouraging the industry to change to local products
- Single cell proteins as fishmeal replacements are still too costly

5. Availability and sourcing of ingredients
5.1 Abuse of feed additives in aquafeeds - the need for regulation
Traceability issues remain an issue with regard to the composition of some feed additives. The composition of many additives is unknown and therefore raises the risk of the inclusion of banned or restricted chemicals. Several recent trade disputes in this regard have led some countries to introduce stringent control measures.

Feed millers are increasingly testing their raw materials to ensure that they are not a source of restricted chemicals (i.e. through contaminated feed ingredients). However in some countries restricted or banned chemicals/drugs are still available and are readily used.

5.2 Sourcing from sustainable feed supplies
There is a growing trend in demand for the use of feed ingredients from more sustainable sources. An emerging opportunity is the use of bone and animal by-product meals which were originally used in livestock feeds. Due to cross contamination concerns these commodities are no longer used by the animal feed industry and may provide an ideal alternative to fishmeal. The availability of these commodities is potentially vast.

5.3 Competition for raw materials with other sectors

Competition with the livestock sector and in some cases with direct human consumption for commodities used in aquafeeds is increasing (e.g. maize, soybean, reduction fisheries, wheat). While it is recognised that there is a difference between food grade and feed grade materials there will be increasing pressure in the future on the use of food grade materials in animal feeds. Moreover, there will be increasing competition for agricultural land for growing human food rather than growing crops intended for animal feeds.

5.4 GMO ingredients

The working group recognized that the use of genetically modified aquafeed commodities is and may become more problematic in future.

WORKING GROUP B THEME: Farm-made aquafeeds (including manures and fertilizers) -opportunities and constraints, availability, feasibility and management

The use of farm-made feeds and fertilizers plays very significant roles in aquaculture production in developing countries. However, it has received inadequate attention hitherto. Recognizing its importance, there is an urgent need to address issues related to farm-made feeds and fertilizers to ensure increased production efficiency and sustainable development of the aquaculture sector. The factors identified that are thought to be of immediate relevance can be categorized under five headings.

These are:

- Policy/guidelines
- Research and development needs
- Extension, application and adoption
- Capacity building; and
- Public and private sector partnerships.

1. Policy/Guidelines

Governments are encouraged to develop and implement appropriate policies with respect to farm-made feeds and fertilizers are developed and effectively implemented. Such possible policies should encompass the following factors and issues:

- use of farm-made feeds and fertilizers should ensure environmental integrity such as the prudent use of trash fish in farm-made feeds and integrating animal husbandry with fish culture;
- encourage the use of locally available raw materials and ingredients;
- in certain regions where use of farm-made feeds is non-existent, encouragement should be given to make use of locally available ingredients to promote the development of aquaculture;
- set quality and safety guidelines for effective use of farm-made feeds and fertilizers;
- provide support for needs based research;
- provide support for the procurement of suitable/appropriate equipment for farm-made feed and fertilizers;
- governments will have to recognize the possible negative impacts/influence of vested interests in the development of the farm-made feed and fertilizer sectors; and
- develop mechanisms for interregional and international cooperation on the use of farm-made feeds.

2. Research and development needs

Recognizing the importance of farm-made feeds and fertilizers in developing countries, there is a need to intensify research and dissemination of outcomes on the following aspects:

- collate and update information on ingredients currently used and potentially usable in farm-made feeds; synthesis be carried out in respect of all available ingredients used on a regional basis taking into consideration factors such as seasonality, nutritional composition, price fluctuations (FAO/NACA/ and other regional organizations and or donor organisations);
- conduct a compilation and detailed review in a number of developing countries on the characteristics (ingredients, composition, methods of preparation, storage, efficacy, economics of performance) of currently used farm-made feeds. Such studies are expected to lead to compilation of better practice approaches on the use of farm-made feeds, on a regional basis (FAO/NACA/ and other regional organizations and or donor organisations);
- national institutions should be encouraged to undertake suitable research on formulation and improvements on proper and safe use of farm-made feeds and fertilizers;
- encourage and stimulate research on the nutritional requirements and feed and feeding related aspects of major cultured species. Relevant findings should be tested on farm before dissemination;
- compile and update available knowledge on the nutritional requirements of major cultured species in different regions (FAO); and
- where appropriate, use should be made of indigenous knowledge.

3. Extension, application and adoption

Organizations that interface with farmers or closely connected with farmers play an extremely important role and should be encouraged and supported in their work with regard to farm-made feeds and appropriate use of fertilizer. Acknowledging that the available extension materials are limited and often lack field testing, there is a need to identify and prepare appropriate extension tools with respect to the use of farm-made feeds. In order to achieve these objectives, the following actions may be taken by national and regional institutions:

- relevant extension materials developed and field tested with due considerations of cultural norms;
- in developing extension materials on the preparation of farm-made feeds and use of fertilizer, indigenous knowledge should be considered and farmers should be appraised of environmental concerns;
- use of mass media (e.g. radio, theatre, TV, newspaper) should be intensified;
- utilize existing successful demonstration units/farm as well as promote innovative farmers and use these farms as extension centres; and
- increased interaction between research and development (R&D) and farmers; and between farmers.

4. Capacity building

The full value of the use of fertilizers and farm-made feeds in rural aquaculture in developing countries has not been fully realized. There is an urgent need for capacity building for research and development and effective extension. These objectives could be achieved through the following actions by national and regional institutions:

- capacity building of extension officers and private service providers and NGOs through, e.g., specialized short term training programmes and workshops
- training on the preparation and use of farm-made feeds and fertilizers; and
- in certain regions such as Africa, there is a need for specialist capacity (e.g. specialized advanced training on fish nutrition and fish feed technology).

5. Private and public sector partnerships

Until now, there has been very little interaction between the private and the public sectors regarding the importance of farm-made feeds and fertilizers for the development of rural and peri-urban aquaculture. The following will facilitate dialogue between the sectors:

- private (small-scale feed makers and other service providers) and public sectors need greater appreciation of the importance of farm-made feeds and fertilizers;
- provide a platform for dialogue between farmers and small scale feed producers and the animal husbandry industry through workshops (FAO/NACA/and other regional organizations and or donor organizations);
- encourage the establishment of farmer cooperatives/associations for on farm-made feed production; and
- provision of technical advisory services by public sector (agricultural agencies), e.g. providing printed/web-based information on supplier/market/price and other available services. To increase the responsibility of the public sector, using examples of lessons learned from other countries (e.g. leaflets, telecommunication, NACA/ACIAR booklet on grouper feed, etc).

The workshop recommended that FAO be tasked to take up the following actions to assist national governments and regional organizations:

- review existing national standards and legislation regarding the dietary nutrient specifications (where they exist) for the manufacture of compound aquafeeds/farm-made aquafeeds for the major cultivated fish species, including the provision of guidelines and advisory material for different farming systems and feed types;
- review existing national mechanisms of incentives, subsidies and taxes affecting the animal feed manufacturing sector and feed ingredient usage, including feed ingredient imports and export/domestic promotion strategies;
- compile available information (in the form of synopses) on the dietary nutritional requirements of major cultured fish species and the feed ingredients currently used within compound/farm-made aquafeeds, including national/regional feed ingredient source books containing information on nutrient composition, quality control criteria, seasonality, and market price;
- encourage the strengthening of national/regional dialogue, exchange of information and research priority setting between researchers/public sector and the aquaculture sector (including farmers and feed manufacturers), through support to the activities of national/regional organizations, the implementation of joint research projects, the establishment of national farmer/aquafeed associations, and the development of web-based information and research networks; and
- strengthen capacity building in aquaculture nutrition and feed technology, including on-farm feed management, for farmers, feed manufacturers, private service providers, researchers and extension workers within developing countries (and in particular within sub-Saharan Africa). This may also respond well to inter-regional cooperation.

ACKNOWLEDGEMENTS

We would like to gratefully acknowledge all staff of the Freshwater Fisheries Research Centre and in particular Mr Miao Weimin, Deputy Director and Associate Professor Yuan Xinhua for their excellent cooperation and hospitality provided during the workshop. The Network of Aquaculture Centres in Asia-Pacific (NACA) is acknowledged for its active collaboration in organizing the workshop. The Ministry of Agriculture, Government of P.R. China is acknowledged for arranging the necessary government clearance for visas of all workshop participants. All participants actively participated in the workshop and contributed during the technical presentations and the working group sessions and we take this opportunity to thank all of them for their time and effort. The kind assistance and active contributions by Dr Simon Funge-Smith, Aquaculture Officer, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand and Dr Melba Reantaso, Fishery Resources Officer (Aquaculture), FAO HQ, Rome, Italy is gratefully acknowledged.

ANNEX I
WELCOME REMARKS PROFESSOR XU PAO, DIRECTOR, FRESHWATER FISHERIES RESEARCH CENTER, CHINESE ACADEMY OF FISHERY SCIENCES, WUXI 214081, CHINA

Ladies and Gentlemen:
Good morning
FAO expert workshop on the use of feeds and fertilizers for sustainable development is now commencing in Freshwater Fisheries Research Center (FFRC), Chinese Academy of Fishery Sciences (CAFS), Wuxi, China. On behalf of Freshwater Fisheries Research Center, I'd like to extend a warm welcome to all the experts from FAO and other different countries.

Freshwater Fisheries Research Center, Chinese Academy of Fishery Sciences is one of the major comprehensive fisheries institutions for research, education/training, and information exchange. In the research activities, FFRC has the main functions oriented toward the basic and applied researches. The key research emphases are on fishery breeding biology and genetics, conservation of biodiversity and fishery stock resources, monitoring and protection of fishery environment, evaluation and management of fishery resources, fish disease prevention and control, carrying capacity and healthy aquaculture, fish nutrition and information exchanges etc.

Asian-Pacific Regional Research and Training Center for Integrated Fish Farming as an important component of Freshwater Fisheries Research Center, has continuously undertaken China-TCDC training courses for 25 years. Over 30 courses have been successfully conducted for more than 1000 participants from 80 countries, besides there have been also a great number of times of international academic workshops, visiting scholar exchanges and research collaborations.

Freshwater Fisheries Research Center is pleased to carry out collaboration in any forms on fishery research, technical training, and human resource development with all the specialists present at the workshop and assures the workshops of logistic services

Finally, I wish in advance the workshop a successful completion and good health of all the guests present at the workshop

Thank you

ANNEX II
OPENING REMARK OF MR LI JIEREN, VICE PRESIDENT OF CHINESE ACADEMY FISHERIES SCIENCE

Good Morning, Ladies and Gentlemen,
On behalf of Chinese Academic of Fisheries Science (CAFS), I would like to welcome all the colleagues, friends and participants, including international and national aquaculture feed and fertilizer experts, to attend this very important workshop in Wuxi and discuss the aquaculture related issues.

China is an important aquaculture country with a long aquaculture development history. Aquaculture has been documented more than 2000 year ago in China. At present, the total fisheries production reached 51 million, which about 67 percent come from aquaculture production. Aquaculture has become a very important component in the animal protein food production.

About 60 percent of natural fisheries resource has been damaged worldwide, it is declining in general and hardly to meet the demand for aquatic products through capture fisheries. Aquaculture contributes significantly to food availability, household food security, income generation, trade, and improved living standards in many developing countries, including China. The development of aquaculture has become more and more important in obtaining aquatic food for the people. Fisheries are transferring from capture fisheries to aquaculture, it just like the transferring agriculture from "collecting" to "farming" and from "hunting" to "animal husbandry". The development of aquaculture not only made its possible for increase of total fisheries production, but provides a complete new concept and efficient measure to reasonable utilization of water resources considering "expended ecosystem". The utilization of capture fishery resources is a process for use of solar energy by phytoplankton, in turn used by aquatic species in low-food chain to high food chain. The relationship for energy conversion and utilization among the species depends completely on a natural process. In aquaculture, feed technologies and various technical measures can be applied in the process of energy and food conversion to substantially improve the conversion ratio and food utilization so that the source of land-based plant feed can be introduced to the production of aquatic products. Therefore, the research and application on aquaculture technologies which consume less cost and energy and maximize aquaculture production will be required for seek of sustainable aquaculture development.

Aquaculture feeds and fertilizers as indispensable parts have played a very important role in the country's fisheries and aquaculture production and development. In China, Modern intensive aquaculture based on the aquaculture feed and nutrition has been practiced for about 20 years. But, China's aquaculture production depends largely on traditional aquaculture. Despite the country's reputation as a producer of large quantity aquaculture products and advanced traditional aquaculture technology, the aquaculture and its feed sector are faced with numerous problems hampering sector growth and development. These constraints include: (i) low-cost traditional pond aquaculture still remains as semi-intensive and poly-culture practice due to the low price of common food fish and slow economic development in rural areas; (ii) the application of a large quantity of single and family formulated feed still dominates aquaculture production; (iii) the aquaculture sector and its production are often developed and increased at the expenses of decrease of arable land areas; and (iv) under a highly-intensive aquaculture condition, the application of high-nutrient feeds and over-feeding practice often cause eutrophication and fish disease breakout in waterbody, and in turn result in environmental pollution and other problems due to lack of experience for special high-value aquatic species and inadequate studies on nutrition physiology and metabolism of target species.

A. The achievements made in animal feed and nutrition research in China

Let me to brief you what work have been done and achievements made in animal feed and nutrition research in China. China has commenced the studies and research on aquaculture animal feed and nutrition since 1980s. The major researches conducted include: nutrition requirement of fish and shrimp and feed formulation, the quality control and inspection of aquaculture animal feeds, alternative source of plant feeds, alternative biological feed and its culture techniques for aquaculture nursery, and biological feed and supplementary feed for polyculture system. These developed technologies are being widely applied in aquaculture production. These major achievements also include:

i) Obtained the nutrition requirements of major cultured-animal species at their different growing stages and the key nutrition parameters of supplementary feeds to provide scientific basis for the formulation of applied feeds;

ii) Developed technical standard and criteria for the quality control and inspection of aquaculture feeds and feed biological comprehensive assessment and established a number of feed inspection agencies at national and provincial levels to standardize the feed production;

iii) Produced several kinds of fish feed additive and pre-mixed feeds to expend the feed sources and improve feed quality;

iv) Produced various sinking and floating artificial feeds and commercial feeds for well-known and special high value cultured-species;

v) Cleared the nutrition value of sources of aquaculture feed and conventional aquaculture feeds and tested the energy value, nutriment and digestibility of various feeds to provide scientific basis for the development of high-efficient and artificial supplementary feeds; and

vi) Commenced the introduction and conversion of international research outcomes and new technologies on the nutrition and feeds for commercial production of high-value marine animal.

B. Priority Areas for China's Aquaculture Feed and Nutrition Research

Future priority research areas on aquaculture feed and nutrition in China include:

i) to further conduct of aquaculture nutrition physiology and metabolism, specifically, the functions of micro-nutriment to provide reliable scientific basis for modifying nutrition requirement, formulating low-cost and high-efficient applied feeds and improving feed conversion ratio;

ii) to strengthen research on the relationships between nutrition and immunity, incretion, environment, aquaculture product and its value;

iii) to further conduct the research on the reduction of release of phosphorous to aquaculture and water system for environment protection and feeding strategy;

iv) to conduct research on formulation technology of alternative artificial microdot supplementary feeds to replace live biological feeds and utilization of sources of plant feed; and

v) for a long term, to conduct research on the technology to produce fish as feed.

As we all aware, aquaculture feeds and fertilizers play a very important role in the aquaculture sector. I fully believe that workshop will generate a number of meaningful and operational recommendations, including policy and institutional recommendations on aquaculture feed and fertilizer research during our discussions. These outcomes of the workshop will eventually accelerate the development of world aquaculture feed and fertilizer sector and promote the sustainable aquaculture development.

As a national research institution, CAFS has its responsibility for important basic and applied research and new- and high- technology developments for fisheries and aquaculture sector. It also plays a vital role in solving key and important sector and development issues within fisheries sector, and conducting national and international fisheries and technology exchange, communications and collaboration programs. At present, CAFS has 9 research centers and 4 multiplication and experimental stations. Therefore, take the opportunity, I would like to invite you and welcome all of you, international and national experts to make our best effort to strengthen our research collaboration in aquaculture feed and fertilizer research and development to achieve our common goal and contribute to world sustainable aquaculture development and poverty reduction. Finally, I would like to wish to have a fruitful and fully successful workshop! Thanks

ANNEX III
FAO EXPERT WORKSHOP ON "USE OF FEEDS AND FERTILIZERS FOR SUSTAINABLE AQUACULTURE DEVELOPMENT"

Wuxi, Jiangsu Province, P.R. China, 18–21 March 2006

Agenda

time	ACTIVITY
17th March	
	Arrival of Participants in Wuxi
18th March - Workshop day 1	
08.00 - 08.30	Registration
Session I: Opening and Welcome Remarks	
08.30 - 09.00	• Master of ceremony – Yuan Xinhua • Election of Chair • Welcome address – Director, Freshwater Fisheries Research Centre • Opening remarks – Vice President, Chinese Academy of Science • Introduction of the participants • Group photograph
09.00 - 09.10	Introduction and Objectives of the Workshop – *Dr Mohammad R. Hasan*
Session II: Presentation of Country Reviews: Study and analysis of feeds and fertilizers for sustainable aquaculture development *Co-chair: Dr Sena De Silva - Rapporteur: Dr Melba Reantaso*	
09.10 - 10.10	Selected country reviews (20 minutes for each presentation) • China: *Mr Miao Weimin* • India: *Dr Syed Ahamad Ali* • Philippines: *Dr Neila S. Sumagaysay-Chavoso*
10.10 -10.30	Coffee/Tea Break
10.30 -11.50	Selected country reviews (20 minutes for each presentation) • Thailand: *Dr Supis Thongrod* • Viet Nam: *Dr Le Thanh Hung* • Egypt: *Dr Abdel-Fattah M. El-Sayed* • Uganda: *Dr Justus Rutaisire*
11.50 -12.30	General discussion on country reviews
12.30 -14.00	Lunch
Session III: Review of Development of Aquafeed Industry *Co-chair: Dr. Albert Tacon Rapporteur: Dr. Melba Reantaso*	
14.00 -15.00	• China: *Ms Liang Mengqing* • India: *Dr Syed Ahamad Ali* • Egypt: *Dr Abdel-Fattah M. El-Sayed*
15.00 - 15.20	General Discussion on review of development of aquafeed industry
15.20 - 15.40	Coffee/Tea Break
Session IV: Presentation of Regional Synthesis	
15.40 - 16.10	Feeds and Sustainability of Asian Aquaculture: *Dr Sena De Silva*
16.10 - 16.40	Developments in sub-Saharan African aquaculture: feeds and fertilizers: *Dr Thomas Hecht*
16.40 - 17.10	Aquaculture feeds in Latin America: a look at key elements at the macro (the industry) and micro (farm practices) levels: *Dr Alejandro Flores Nava*
17.10 - 18.00	General Discussion
18.00 – 20.30	Depart to Wuxi town for reception dinner

19th March - Workshop day 2	
Session V: Presentation of Case Study on Economics of Aquaculture Feeding Systems *Co-chair: Dr Alejandro Flores-Nava - Rapporteur: Dr Thomas Hecht*	
08.30 - 08.50	Case study on the use of farm-made feed versus commercially formulated pellets for *Pangasiid* catfish in the Mekong delta, Viet Nam: *Dr Le Thanh Hung*
08.50 - 09.10	The economics of small-scale aquaculture feeding systems in China: *Mr Yuan Xinhua*
09.10 - 09.40	An economic analysis of aquaculture feeding systems: a synthesis of three Asian countries: *Dr Walfredo Raquel Rola*
09.40 -10.10	Discussion
10.10-10.30	Coffee/Tea Break
Session VI: Invited Presentation and Global Synthesis	
10.30 -11.00	Invited presentation: Reducing waste production of aquaculture by improvement of feed formulation and feeding regime- *Dr Shouqi Xie*
11.00 -11.30	Feeds and nutrients for sustainable aquaculture development within developing countries: a global synthesis: *Dr Albert G.J. Tacon*
11.30 -12.00	General Discussion
Session VII: Working Group Discussions	
12.00 -12.30	Mechanisms and guidelines for Working Group (WG) Discussions: *Dr Simon Funge-Smith*
12.30-14.00	Lunch
14.00 -18.00	Working Groups break up for discussions

20th March - Workshop day 3	
Session VII (cont.): Working Group discussions *Co-chair: Dr Mohammad R. Hasan - Rapporteur: Dr Simon Funge-Smith*	
09.00 – 10.30	Working Groups continue and preparation for plenary presentation
10.30 -10.45	Coffee/Tea Break
10.45 -11.15	Working Group I – presentation to plenary
11.15 -12.15	Working Group II - presentation to plenary
12.15 – 12.30	Short plenary discussion to prepare for afternoon session
12.30 -14.00	Lunch
14.00-15.00	General Discussion Working Group Presentations Identification of key points for action
15.00 -16.00	Working Group Chairpersons, Rapporteurs and Technical Secretariat to finalize Workshop Recommendations
Session VIII: Presentation of Final Workshop Recommendations in Plenary *Rapporteur: Dr Simon Funge-Smith*	
16.00 -17.30	Short presentation of summary recommendations of the workshop Discussion Closing
18.00 – 20.30	Depart to Wuxi for closing dinner

21st March - Workshop day 4	
08.30 -18.30	All-day field visit to feed machinery manufacturing plant, feed mill and fish farm

22nd March	
	Participants depart Wuxi

ANNEX IV
PROCEDURES FOR WORKING GROUP SESSIONS

For the working sessions, workshop participants were divided into two groups. Each group examined one or more thematic area(s) assigned to them, and were requested to identify critical issues and prepare specific recommendations and follow up actions and to present these in the final plenary session. A number of background documents were circulated among the participants prior to and during the workshop.

Thematic areas assigned to the Working Groups

Working Group A: Industrial aquafeed- development of the industry, impact of availability of protein sources, alternatives and their feasibility

Working Group B: Farm-made aquafeeds (including manures and fertilizers) -opportunities and constraints, availability, feasibility and management

Recognizing that aquaculture practices and farming systems vary widely between and within regions (Asia, Africa and Latin America) working group participants were requested to consider the following general issues during their discussions:

- limited land area will prohibit further horizontal expansion of aquaculture in Asia;
- resources (feed and fertilizers) are limited and competition with other resource users (poultry, livestock and crop) will increase;
- bulk of aquaculture production in Asia and over 80 percent of fish produced in Africa depend on farm-made aquafeeds and this is likely to continue in the foreseeable future;
- in Asia, market price and demand often makes it uneconomic to use industrial feeds while in Africa it is constrained by economies of scale and the lack of critical mass; and
- farm-made feeds are rarely used in Latin America and greater use of farm-made feeds may provide opportunities for small-scale farmers.

The working groups were specifically also requested to consider the following issues:

Working Group A: Development of the aquafeed industry

- Dependence of industrial aquafeeds on key feed ingredients (fishmeal, fish oil, SBM)
- Impacts of availability of key feed ingredients on industrial feed based aquaculture
- Realistic alternatives of fishmeal and fish oil (except SBM) and the best approach to translate the results into practise
- Quality assurance of locally produced industrial feed

Working Group B: Farm-made aquafeeds

- Improving feed quality
- Economic and environmental issues related to the use of farm-made aquafeed vs. industrially manufactured feeds.
- Improvement in feeding and feed management practices
- Development of location/region-specific appropriate farm-made feed formulations through focused research.
- Extension and support services to small (farm-made)- to medium-scale aquafeed producers to improve their production processes and technologies

After the general discussion of the working group presentations in the plenary the WG Chairpersons, Rapporteurs and the technical secretariat finalized the workshop recommendations that were approved during the final plenary session.

ANNEX V
LIST OF PARTICIPANTS

AUSTRALIA Dr Sena S. De Silva, Professor, School of Ecology and Environment, Faculty of Science & Technology, Deakin University Warrnambool, Victoria, Australia. Tel. +61 (3) 556 33527. E-mail: sena@deakin.edu.au	**MEXICO** Dr Alejandro Flores Nava, Rector, Universidad Marista de Merida, Calle 14 No. 128 x 5 y 9 Fracc. Montecristi, Mérida, Yucatan, 97000 Mexico, Tel. 52-999-9412026, Fax: 52-999-9410307. E-mail: aflores@marista.edu.mx
CHINA Miao Weimin, Deputy Director, Freshwater Fisheries Research Centre, Qitang North No. 1, Wuxi, P.R. China, 21408. Tel. (86) 510-5878390. Fax: (86)510-5555112/ (86)510-5553304. E-mail: miaowm@ffrc.cn, wmmiao@public1.wx.js.cn	**PHILIPPINES** Dr Neila S. Sumagaysay-Chavoso, University of the Philippines Aquaculture Society, Gabinete Residence, Miramar Subdivision, Jaro 5000, Iloilo City, The Philippines. Tel. No. (063) 335096700. E-mail: neila_sc@yahoo.com.sg
Yuan Xinhua, Associate Professor, Freshwater Fisheries Research Centre, #9. Shanshui Xi Rd., Wuxi, Jiangsu Province, P.R. China 214081. Tel. +86-510-5555796/2281121; Fax: +86-510-5555796. E-mail: yuanxh@ffrc.cn	Dr Walfredo Raquel Rola, Department of Community and Environmental Resource Planning, College of Human Ecology, UPLB, Los Banos, Laguna, Philippines 4031. Tel. +63-049-536-1622. E-mail: wallyrola@yahoo.com
Ms. Liang Mengqing, Yellow Sea Fisheries Research Institute PO Box: 266071,106 Nanjing Road,Qingdao, P.R. China. E-mail: liangmq@ysfri.ac.cn	**SOUTH AFRICA** Dr Thomas Hecht, Professor Emeritus, Dept. Ichthyology & Fisheries Science, Rhodes University, Grahamstown, South Africa Tel. +27 (0) 46 6038415 (W) +27 (0) 46 6751010 (Home). E-mail: T.Hecht@ru.ac.za
Dr Shouqi Xie, Institute of Hydrobiology, The Chinese Academy of Sciences, Wuhan, Hubei, 430072 P.R. China, Tel/Fax: +86 27 68780667. E-mail: sqxie@ihb.ac.cn, sqxie@public.wh.hb.cn	**THAILAND** Dr Supis Thongrod, Director, Coastal Aquatic Feed Research Institute, Department of Fisheries, 41/14 Moo 9, Bangphra District, Sriracha, Chonburi Province 20110, Thailand. Tel. 66-38-312532, Fax: 66-38-312532. E-mail: supist@fisheries.go.th, supisthongrod@yahoo.com
EGYPT Dr Abdel-Fattah M. El-Sayed, Professor, Oceanography Department, Faculty of Science, Alexandria University, Alexandria, Egypt. Tel. 00203-4273858; 002012/1699648, E-mail: a_elsayed50@yahoo.com	**UGANDA** Dr Justus Rutaisire, Senior Lecturer, Makerere University, Department of Wildlife and Animal Resources Management, Faculty of Veterinary Medicine, P.O. Box 7062, Kampala, Uganda. Tel. +25677501227/+25677634077, Fax +25641533402. E-mail: jruta@mulib.mak.ac.ug; jusruta@yahoo.com
INDIA Dr Syed Ahamad Ali, Principal Scientist & Head, Nutrition Genetics and Biotechnology Division, Central Institute of Brackishwater Aquaculture (CIBA), 75, Santhome High Road, RA Puram, Chennai 600 028, India, Tel. 091-44-24618817, 24616948, 24610565, Fax: 091-44-2461031. E-mail: Ali_madras@yahoo.com, ciba@tn.nic.in	**UNITED STATES OF AMERICA** Dr Albert G.J. Tacon, Aquatic Farms Ltd, 49-139 Kamehameha Hwy., Kaneohe, Hawaii 96744 United States of America. Tel. +1-808-239 2929, Fax: +1-808-235 0177. E-mail: atacon@hawaii.rr.com; AGJTACON@aol.com

VIET NAM Dr Le Thanh Hung, Vice Dean, Faculty of Fisheries, Nong Lam University, Linh Trung Ward, Thu Duc District, HCMC, Viet Nam, Tel. 84-8-7220733/ 84-8-8657570. E-mail: lthungts@hcm.vnn.vn	**NETWORK OF AQUACULTURE CENTRES IN ASIA-PACIFIC (NACA)** Zhuo Xiaowei, Programme & Operation Manager, Network of Aquaculture Centres in Asia-Pacific, P.O. Box 1040, Kasetsart Post Office, Bangkok 10903, Thailand Tel. +66-(0)2-5611728 ext 111; Mobile: +66-(0)9-8153750, Fax: +66-(0)2-5611727. E-mail: xiaowei.zhou@enaca.org
FAO REGIONAL OFFICE FOR ASIA AND THE PACIFIC (FAORAP) Dr Simon Funge-Smith, Aquaculture Officer, FAO Regional Office for Asia and the Pacific, 39 Phra Athit Road, Bangkok 10200, Thailand. Tel. +662-6974149, Fax:+662-6974445. E-mail: Simon.Funge-smith@fao.org	**NON-GOVERNMENTAL AND PRIVATE ORGANIZATIONS (NGOs)** Dr Chawalit Orachunwong, Chareon Pokphand Foods Co. Ltd., 69/1, M4, Tambon Klongjig, Bang-Pa-In Ayudhaya Province, Thailand 13160. E-mail: fishtech@loxinfo.co.th
FISHERIES DEPARTMENT, FAO headquarters Dr Melba Reantaso, Fishery Resources Officer (Aquaculture), Aquaculture Management and Conservation Service, Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00153 Rome, Italy, Tel. (39) 06 570 54843, Fax: (39) 06 570 53020. E-mail: Melba.Reantaso@fao.org	Dr Michael Cremer, Technical Director-Aquaculture, U.S. Soybean Export Council, 9705 Eagle Creek Road, Leavenworth, WA 98826, United States of America, Tel. 509-548-5863, ; c/o American Soybean Association - International Marketing, 1802 SITC, No. 2201 Yanan Xi Lu, Shanghai, P.R. China 200336, Tel. 86-21-621. E-mail: mycremer@earthlink.net
Dr Mohammad R. Hasan, Fishery Resources Officer (Aquaculture), Aquaculture Management and Conservation Service, Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00153 Rome, Italy, Tel. (39) 06 570 56442, Fax: (39) 06 570 53020. E-mail: Mohammad.Hasan@fao.org	

ANNEX VI
TECHNICAL SECRETARIAT

A technical secretariat comprising of Dr Mohammad R. Hasan (Aquaculture Management and Conservation Service, FAO Fisheries and Aquaculture Department), Dr Simon Funge-Smith (FAO Regional Office for Asia and the Pacific) and Dr Melba B. Reantaso (Aquaculture Management and Conservation Service, FAO Fisheries and Aquaculture Department) was responsible for technical coordination.

This technical paper provides a comprehensive overview of feed and fertilizer use for sustainable aquaculture development in developing countries. It comprises a series of review papers, including eight country reviews from Asia, six country reviews from Africa, one case study report from Asia, three regional reviews (Asia, Latin America and sub-Saharan Africa), a global synthesis as well as the final report of the FAO Expert Workshop on Use of Feed and Fertilizer for Sustainable Aquaculture Development, held in Wuxi, Jiangsu Province, China, 18–21 March 2006. The country reviews provide an overview of the current status of aquaculture, a synthesis of the availability, accessibility and use of feed and fertilizer resources in relation to the diversity of farming systems and practices and an analysis of the nutritional, economic and social constraints of using these inputs. The regional reviews provide a synthesis of the country reviews by considering production trends and feed and fertilizer use from a wider geographic perspective and also analyse the projected expansion of the aquaculture sector in relation to the future availability of input commodities. The global synthesis provides a general overview and summarizes the future challenges facing the sector with respect to the use of feeds and fertilizers.

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