for feed and management. Marketing based on two size grades was found to profitable and therefore advantageous for farmers of Kuttanad for polders with culture duration of six months. But for coconut garden channels where the culture duration extends above 10 months, the six-grade structure was profitable.

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Applications of nutritional biotechnology in aquaculture

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Nutritional biotechnology in aquaculture

Globally, consumption of food fishes is projected to reach 165 million tonnes by 2030. As wild catch fisheries are now approaching full exploitation worldwide, a large part of this increase will have to come from aquaculture. The identification of alternative fish species and suitable feed ingredients for their diet formulations has therefore become very important.

The main goal of fish nutrition as a scientific discipline is to produce feeds that support good growth rates while maintaining fish health and quality, resulting in a safe and healthy product for the consumer at least cost. In this regard many scientists are studying the safe utilization of nutrients and their interactions when alternative feed ingredients from plants are used to substitute for traditional (and expensive) fish meal and oil, as well as evaluating alternative marine ingredients. Research focuses on issues such as the characterization of nutrient effects on brooders fish, eggs, larvae, juveniles and at different stages of growth. Measurements include nutrients effect on growth, feed utilization, digestibility, alterations in metabolic pathways, fish health and welfare parameters, nutrient bioavailability and retention. Modern tools within genomics and proteomics are gradually being taken up and focused, giving the opportunity to discover novel pathways and effects of nutrients.

The aquaculture feed sector of India has made tremendous developments during the last two decades. At present about 20 million tones of manufactured aqua feed are being used in aquaculture sector, of which the majority is consumed in shrimp culture (Chandrapal, 2005). If the rapid growth of aquaculture persists, the feed requirement may increase many fold. Hence, more scientific understanding and interventions are required for sustainable aquaculture of the country.

Sustainable commercial carp feed production has became a challenge to the aquaculture nutritionists. It has been estimated that a feed with FCR 1.3 could make a commercial carp feed sustainable. Exploration of novel genes related to growth enhancement and use of different nutraceuticals have raised the hope of achieving that target. Isolating a potential growth hormone gene and subsequent transfer of that gene to enhance the fish production is approaching near to reality. Addition of new immuno-stimulants in aqua feed has increased the possibility of safer production through high-tech aquaculture. Strategies for increasing utilization of cheaper nutrients like carbohydrate by various technological interventions and addition of feed attractants paved the way for developing lower cost feeds sustainable carp culture (Gopakumar, 2003). Currently, quality enhancement of fish flesh by dietary and gene manipulation is a focused area of research in fish nutrition.

Besides feed development, feed management and feed quality are critical factors for profitability of fish farming, especially in intensive aquaculture. A biologically ideal feed may not be economically viable if feed management is poor. A balanced knowledge on fish nutrition and feed management is of paramount importance for sustainable fish production. The following are the priority areas of research in fish nutrition:

- Nutritional requirement of fishes with respect to growth.
- Selection of proper feed ingredients.
- Energy requirements in fish.
- Feed formulation and preparation.
- Feed processing and feeding techniques.
- Carbohydrate utilization as protein sparing effect in fish nutrition.
- Omega-3 fatty acids in nutrition and health.
- Nutraceuticals in fish nutrition.
- Fish nutrition, biochemical and physiological responses in extreme environmental stresses.
- Quality control and storage of feed ingredients.

- Anti-nutritional factors, their detoxification and pathology.
- Feed left -over & waste vis-a-vis water quality management.
- Molecular strategies to enhance fish flesh quality and quantity.

Biotechnology is also helping to answer some of the technical and environmental concerns of fish farming including aquaculture nutrition. Many of these centre around what the fish eat. Over the last decade, the world has witnessed spectacular growth in the aquaculture industry of many developing countries. It is further anticipated that world aquaculture production will continue to increase. Since nutrition and feeding play a pivotal role in sustainable aquaculture and since feed constitutes about 40-50% of total cost of aquaculture production. Use of nutritionally balanced and complete formulated feed will continue to play a dominant role in finfish and shellfish production. Hence, alternative and biotechnologically improved feed ingredients should be sought along with improvements in pond management and manipulation of pond productivity.

Right now, the most common protein source for many fish diets is fish meal, a byproduct of fish processing, used because of its high quality protein content. However, it has some disadvantages. In addition to its high cost, it contains levels of phosphorus far beyond the requirement for optimal growth in fish leading to potential environmental concerns. The excess phosphorus released into the water can cause problems such as eutrophication or excess algae growth.

Plant proteins as alternatives to fish meals

Plant protein has the potential to decrease the problem of phosphorus pollution, since plants do not contain such high phosphorus levels. Moreover, the use of plant protein as a feed ingredient can help to reduce the burden on fish meal supplies. As a result of these concerns, researchers are using biotechnology to produce alternative plant-based protein sources suitable for use in aquaculture.

However, the use of plant-derived materials such as legume seeds, different types of oilseed cake, leaf meals, leaf protein concentrates and root tuber meals as feed ingredients is often limited by the presence of a wide variety of anti-nutritional substances (Fournier et al., 2005). Plant proteins often require processing to remove these substances, which may be produced by plants as natural defence mechanisms. Important among these are protease inhibitors, phytates, glucosinolates, saponins, tannins, lectins, oligosaccharides and non-starch polysaccharides, phytoestrogens, alkaloids, antigenic compounds, gossypols, cyanogens, mimosine, cyclopropenoid fatty acids, canavanine, antivitamins, and phorbol esters. These compounds must be destroyed during processing to prevent harm to the fish. Problems associated with anti-nutritional factors can also be solved by producing feed enzymes to counteract them. Phytase is one example, which can help fish make the best use of the phosphorous available in a plant-protein based feed. One of the most exciting technological developments has come from the ability to manipulate the plant genome to produce products economically for use in aquaculture. The use of genetically modified crops to eliminate anti-nutritional factors and increase specific nutrients (limiting amino acids, n-3 fatty acids, etc.) is now possible. The packaging of genetically engineered proteins in corn seed to produce very inexpensive oral vaccines is also being pursued.

Feed additives

Adding specific nutrients to feed can improve animal digestion and thereby reduce feed costs. A lot of feed additives are being currently used and new concepts are continuously developed with the help of biotechnology.

Utilization of plant fibres in fish feed through enzymes

Although enzymes have been in use for a long time in other applications such as detergents, textiles, baking and brewing, their use in the animal and fish feed has been a recent phenomenon. This is because enzymes need to be designed to suit the appropriate application. Industrial enzymes are mainly produced from microorganisms by a process of fermentation and extraction. These enzymes can be produced in large quantities from genetically modified microbes with desired properties to make them economically viable. Feed enzymes need to be robust to stand variations in pH and temperatures. They need to have high temperature stability to withstand pelletization and also have a long shelf life. Over the years, feed enzymes have been going through an evolution from liquid to powder to granules in their product forms in order to make them more heat stable. Lately the granulation technology has been developed in a way that the enzyme molecules are coated with an inert material like cellulose and wax to give the enzyme full protection. This technology helps the enzyme to achieve longer shelf life and is most suitable for pelletized feed. In Europe and Australia, feed enzymes have been used for nearly a decade but their usage in Indian fish diets has been only in recent years because the technology for the production of these enzymes was not well developed in India.

Several alternate feed sources like sunflower, rapeseed and safflower can provide protein, and sorghum, millets or rice bran for energy could be used as feed ingredients if supplemented by substrate-specific enzymes. Cell wall composition of these high fiber feed ingredients show that they contain large amounts of arabino-xylans, pectic polysaccharides and some cellulose. Use of specific enzymes like xylanase, pectinase and cellulase could allow breakdown of the fibre releasing energy as well as increasing the protein digestibility due to better accessibility of the protein (Alford et al., 1996). In this way the feed cost could be reduced and the protein levels in the feed a increased. The scope for increasing the use of enzymes in the coming decade is certainly there when high quality enzymes become available with more predictable performances.

Phytase in aquafeed

One of the enzymes that has really caught on in India is phytase, an enzyme that breaks down the indigestible phytic acid (phytate) in cereals and oilseeds and releases digestible phosphorus. It has been known for several decades however the feed industry could not use it economically due to its high production costs. Microbial phytase became commercially available in 1990s as the result of biotechnological improvements.

Phytase reduces the use of expensive supplemental inorganic phosphorus such as dicalcium phosphate (Jongbloed et al., 2000). Phytase releases minerals (Ca, Mg, Zn and K), amino acids and proteins, which are complexed with the phytate molecule. Phytate itself is an anti-nutritive factor, which when hydrolysed gives better performance in animals. Today, a substantial numbers of farmers in India are using phytase to reduce the cost of their feed. One interesting observation made from the environmental point of view is in coastal region of Andhra Pradesh. Since phytase has been used in the poultry and aquaculture industries farmers have been benefiting from better control over algal blooms due to the reduction in ground water phosphorus levels. This shows that the phosphorus content in the poultry litter has come down due to usage of phytase which ultimately leads to the reduction of phosphorus in ground water.

Aqua feed manufacturers are also looking into the possibility of using phytase to release the non-available phosphorus from deoiled rice bran, Soya and wheat (Boling et al., 2000). There are various enzyme formulations available in the market with varied activities. Because the enzymes used by the feed industry are produced by different microorganisms, the enzyme characteristics as well as the composition of enzymes would be different. The manufacturer by experience and good quality control can guarantee consistent results. However, comparison of enzyme products is difficult except by in vivo testing. Each microorganism produces enzymes with different optimum pH values, different optimum temperature of operation and different affinity for the substrate in feed. It has not yet been possible to develop an in-vitro method that can predict in-vivo performance.

At present, most of the enzyme products in India are directly imported or the individual enzymes are imported and formulated. These enzymes attract import duty, making their usage expensive. There are very few companies producing enzymes in India due to lack of technology as well as appropriate seed organisms. Most of the multinational enzyme companies have spent years in R & D efforts for development of appropriate enzymes. India needs to look into these aspects and invest in enzyme production biotechnology units in the near future in order to make them economically viable.

Improving expression of the phytase gene in plants is underway as a means to commercially produce phytase, as in biofarming in which plants such as alfalfa are used as “bioreactors” and also by developing plant cultivars that would produce enough transgenic phytase so that their additional supplementation in grain or meals is not necessary.

Micro-nutrients and vitamins in fish feed

The absorption and availability of inorganic trace minerals such as zinc, cobalt, calcium etc., varies depending upon the nature of the minerals (sulphate, oxide or carbonate), their solubility and ionization. Trace minerals are now being attached to oligopeptides to make them more bioavailable. Commercial preparations of proteinated selenium and chromium are used in poultry production. In the case of vitamins, due to varying availability and stability of vitamins in ingredients, supplemental vitamins are widely incorporated in diets. These vitamins are much more stable than naturally occurring forms. Stability is achieved through the application of advanced technologies which involve preparation of biologically active derivatives, coating technologies, carriers and diluents (Bamji, and Lakshami, 1998).

Nutraceuticals

Nutraceutical implies that the extract of food is demonstrated to have a physiological benefit or provide protection against a disease and/or improve growth. Functional foods are defined as being consumed as part of a usual diet but are demonstrated to have physiological benefits and/or reduce the risk of disease beyond basic nutritional functions. Nutraceuticals are often used in nutrient premixes or nutrient systems in the food. In aquaculture, application of nutraceuticals includes addition of feed additives in feed such as antioxidants, vitamins, minerals, and carotenoids etc (Brower, 1998).

Nutraceuticals are also extracted from many fishes including omega-3 oil, chitosan and glucosamine, originally derived from waste products. Hundreds of tons of marine by-products are available annually which are driving force for both research and commercialization in the area of marine nutraceuticals.

Dietary amino acids through GMOs

Essential amino acids are added as supplements to the feed improve the balance of the amino acid profile. Since the amino acid profiles of feed ingredients do not normally match the profile of amino acid requirements of the target species, supplemental essential amino acids are added to improve protein utilisation. The new trend is to formulate diets on digestible amino acid levels thereby reducing the requirement for protein. So far lysine and methionine have been used as supplements. Lysine is produced by microbial fermentation and methionine is chemically synthesized. Genetically enhanced micro-organisms are being used to produce threonine and tryptophan on a commercial basis and soon other essential amino acids also would become available. Using all these amino acids it is possible to lower dietary crude protein level by 2 – 3 %, which is a substantial saving for the farmer. The concept of an ideal protein blend from GM feedstuffs and feed additives (such as amino acids and enzymes) will greatly help with decreasing the amount of nitrogen excreted in animal waste (Halver, 2002).

Toxin binders in fish feeds

Feed manufacturers have been incorporating various mold inhibitors in their diets to prevent mycotoxin formation. A variety of physical, chemical and biological approaches to counteract the mycotoxin problem have been reported, but large scale, practical and cost effective means for detoxification of mycotoxins containing feed stuffs are limited. Most of them are fungistats and not fungicides that only inhibit growth of molds and do not inactivate any toxins already present (Tuan et al. 2002). Present day methods generally use organic acids and their salts like propionic acid or adsorbents like bentonites, zeolites, hydroxyl aluminosilicates. In the future, biotechnology based products like microbes, herbal extracts or esterified glucomannan could be used. Extracts of garlic, onion, turmeric, neem have been shown to exert antifungal activity or inhibit aflatoxin production. Identification of the active ingredients would help in the development of genetically modified herbs with enhanced activities to make them cost effective.

Fish feed attractants

Colour, smell, odour, taste and flavour of several food and feed stuffs play an important role in attraction of animals towards a particular feed (Kozasa, 1986). New strategies including from the Central Institute for Fisheries Education, Mumbai, are being adopted to isolate, purify and utilize the various active principles and chemical ingredients from indigenous plants and traditional herbs as fish attractants in feed. This may help in reducing feed waste and scheduling of feeding frequency.

Probiotics in fish nutrition

Microorganisms are naturally present in the digestive system of the animals. Some microbes aid digestion, others can potentially cause pathogenesis. The microbial ecology of the gut merits greater attention due to its implications for nutrition, feed conversion and disease control. Use of antibiotics disturbs the microbiological balance of gut flora eliminating most of the beneficial flora. On stopping antibiotic treatment, pathogens begin to reestablish themselves in the intestine. Overgrowth of these organisms and subsequent invasion of the system by pathogenic organisms cause inflammatory, immunological, neurological and endocrinological problems. Using probiotics can help build up the beneficial bacteria in the intestine and competitively exclude the pathogenic bacteria (Gatesoupe 1999). Probiotic bacteria also release enzymes, which help in the digestion of feed. The concept of using probiotics in animal feed particularly poultry and aquaculture is slowly becoming popular. The common organisms in probiotic products are *Aspergillus oryzae*, *Lactobacillus acidophilus*, *L. bulgaricus*, *L.plantarium*, *Bifidobacterium bifidium*, *Streptococcus lactis* and *Saccharomyces cerevisiae*. These products can be administered through water or incorporated in the feed. Probiotics have been particularly useful in the early stages of chick growth since the gut of the newly hatched chick is sterile and administering probiotics through water at this stage helps to build up beneficial bacteria much faster than the normal course.

The most important quality parameter of probiotics is that the vegetative or the spore forms have to be viable to be able to multiply in the gut. Secondly they should be resistant to antibiotics, which are administered so that the gut ecology could be maintained. Genetic engineering would help develop probiotics with special properties like secreting enzymes and vitamins in large quantities. Such products would be the future generation feed additives.

Probiotics have also been used in a big way as pond cleaners in aquaculture. Probiotic bacteria directly uptake or decompose the organic matter or toxic material and improve the quality of water. The microbial cultures produce a variety of enzymes like amylase, protease, lipase, xylanase and cellulase in high concentrations than the native bacteria, which help in degrading waste. These bacteria have a wide range of tolerance for salinity, temperature, pH which usually exists in aquaculture operations. The use of antibiotics in aquaculture is banned due to rejection of export consignments of marine products. Hence usage of probiotics is propagated to counter the effect of viral and bacterial infections in commercial aquaculture. The pond probiotics also sometimes contain a special blend of denitrifying bacteria that remove the algae's primary source of food, nitrogen from the water. This drastic reduction in nitrogen concentration makes it difficult for the algae to bloom (Douillet and Langdon, 1994). The balance between phytoplankton, zooplankton and beneficial bacteria during culture period play a crucial role in the maintenance of pond health.

Prebiotics in fish nutrition

The concept of prebiotics in aquafeed is fairly recent. Prebiotics are basically feed for probiotics that are resistant to attack by endogenous enzymes and hence reach the site for proliferation of gut microflora. Some of the prebiotics that are currently used in animal feed are mannan-oligosaccharides (MOS), fructo-oligosaccharide and mixed oligo-dextran. Mannan-oligosaccharides are mainly obtained from cell walls of yeasts. Other sources of MOS are copra or palm kernel meal. MOS interferes with the colonization of the pathogens. Cell surface carbohydrates are primarily responsible for cell recognition. Bacteria have lectins (glycoprotein) on the cell surface that recognize specific sugars and allow the cell to attach to that sugar. Binding of *Salmonella*, *E.coli* and *Vibrio* sp. is shown to be mediated by a mannose specific lectin like substance present on the bacterial cell surface. Similarly fructo-oligosaccharides from chicory have been used as prebiotics to competitively exclude pathogenic bacteria (Xu et al. 2003). The pH of the lumen gets reduced thus preventing the entry of pathogenic bacteria. The concept of using prebiotics has not yet been accepted but the advantages of prebiotics are that it can stand high pelletizing temperatures in the feed and also have a long shelf life.

Quality management and detection of contaminants in fish feeds

Modern and biotechnological tools like PCR, biomonitoring and DNA/gene based diagnostics could be developed and used for detection of *Aspergillus* fungi, *Salmonella* species, mycotoxins and other contaminants in fish feeds and feeding environment. UV/visible spectrophotometric, HPLC and

Ag:Ab based detective technologies could also be utilized for detection of several other health hazardous contaminants, heavy metals, xenobiotics, antibiotics, pesticides and steroids etc., in fish feeds.

Growth Improvement and enhancement of quantitative traits in fishes

Enhancement of natural growth rates for fish in aquaculture has been extensively explored, with gains arising from improvements in husbandry, nutrition and genetic selection (Pennel and Barton, 1996). Growth enhancement can provide advantages for aquaculture by shortening production times, enhancing feed conversion efficiency, and controlling product availability. Endocrine approaches to controlling growth have also been extensively explored, principally applications of somatotropins such as growth hormone (GH), prolactin, and placental lactogen, insulin- like growth factor-1, thyroid hormones and sex steroids (Mclean and Devlin, 2000). In the recent past, there are instances both in India and abroad where growths of fish have been increased by incorporation of growth hormone gene with strong promoters.

Highly unsaturated fatty acids (HUFA) and qualitative enhancement of fishes

Highly unsaturated fatty acids (HUFA) are receiving considerable attention due to their involvement in human health. Fish is an important dietary source of long chain C20 and C22 highly unsaturated fatty acids (HUFA) (Ackman 1980), which are crucial to the health of higher vertebrates also. They play pivotal roles in number of biological functions including cardiovascular functions, neural development, eicosanoid signaling (Funk, 2001), regulation of gene expression and ion channel modulation (Kang et al., 2004).

Traditional emphasis has been on dietary lipids and oils because of their effects on lipid composition, in particular that of the lipoproteins. The classical way by which lipids were evaluated, however, gradually changed in the last decade as it became evident that fatty acids themselves regulate lipid homeostasis not only at the level of the lipids interacting with proteins, but also on the genetic level by affecting gene expression. Changes in the lipid content at high concentration are the major cause for several diseases, i.e., obesity, coronary heart disease and cancer (Kushi et al., 1997). Earlier studies clearly showed that risk of coronary heart disease was greatly reduced in populations where fish is major portion of food.

In the recent years research work has been initiated to conduct molecular analysis and characterization of delta-6 fatty acyl desaturase genes from several fin fishes which are involved in biosynthesis of omega-3 and omega-6 PUFA (Clarke et al., 1998).

Genetic manipulation in bacterial biofilms - a source for fish nutrition, live vaccines and anti-biofouling agents

Molecular approaches to characterizing biofilm structure and development offer considerable potential for finding novel biofouling and disease prevention strategies in enhancing aquatic productivity. It is now possible to determine the genes and pathways involved in regulation and synthesis of bacterial adhesive polymers and virulence antigens. Considerable progress has been made in understanding the nature and expression of surface polymers and bacterial vaccines produced by microorganisms such as the nitrogen-fixing *Rhizobium* species and the opportunistic pathogen *Pseudomonas aeruginosa* etc. Similar approaches can be applied to marine biofilm bacteria, to find the genetic determinants of adhesive production and the environmental factors that regulate synthesis (Harwood and Gibson, 1988).

Biomaterials also hold promise for counteracting biofouling, which long has been recognized as an extensive and costly problem. Bacterial biofilms form slime layers that increase drag on moving ships, interfere with transfer on heat exchangers, block pipelines, and contribute to corrosion on metal surfaces. Bacterial and microalgal colonization of surfaces is accompanied by settlement of invertebrate larvae and algal spores, eventually leading to “hard fouling” and the need for costly cleaning. The most effective anti-fouling coatings have utilized toxic chemicals, such as copper and organotins. There is an urgent need for non-toxic biofouling control strategies, due to heightened recognition of the impact that toxic coatings can have on the environment. Research is needed on the attachment mechanisms of marine organisms and the natural products they employ to prevent fouling of their own surfaces.

Developments of biosensors by genetic engineering for aquatic environment monitoring

Marine organisms can provide the basis for development of biosensors, bio-indicators, and diagnostic devices for medicine, aquaculture, and environmental monitoring. One type of biosensor employs the enzymes responsible for bioluminescence. The lux genes, which encode these enzymes, have been cloned from marine bacteria such as *Vibrio fischeri* and transferred successfully to a variety of plants and other bacteria. The lux genes typically are inserted into a gene sequence, or operon, that is functional only when stimulated by a defined environmental feature (Goldsmith et al., 2006). The enzymes responsible for toluene degradation, for example, are synthesized only in the presence of toluene. When lux genes are inserted into a toluene operon, the engineered bacterium glows yellow-green in the presence of toluene. This genetically engineered system “reports” that biodegradation of a specific chemical, in this case toluene, is proceeding. Another type of biomonitor that holds great promise is the gene probe, which can be used to identify organisms that pose health hazards or may be useful in research. Specific gene probes can be employed, for example, to detect human pathogens in seafood and recreational waters; fish pathogens in aquaculture systems; microorganisms capable of mediating desired chemical transformations (e.g., toxic chemical degradation, CO_2 assimilation, metal reduction); and specific fish stocks in fish migration and recruitment studies.

Bioremediation for improving aquaculture

Bioremediation shows great promise for addressing problems in aquatic environments wherein fishes are allowed to grow and fed with formulated and natural feeds in aquaculture. These problems include catastrophic spills of oil in harbors and shipping lanes and around oil platforms; movement of toxic chemicals from land, through estuaries, into the coastal oceans; disposal of sewage sludge in rivers/water bodies, bilge waste, and chemical process wastes; reclamation of minerals, such as manganese; and management of aquaculture and seafood processing waste (Queiroz and Boyd, 1998)

Nutrigenomics

Nutrigenomics is the study of molecular relationships between nutrition and the response of genes, with the aim of extrapolating how such subtle changes can affect animal health. Nutrigenomics focuses on the effect of nutrients on the genome, proteome, and metabolome. It is applying the sciences of genomics, transcriptomics, proteomics and metabolomics to animal nutrition in order to understand the relationship between nutrition and health. Nutrigenomics has also been defined as the application of high-throughput genomic tools in nutrition research (Müller and Kersten, 2003). This refers to genetic tools that enable literally millions of genetic screening tests to be conducted at a single time. When such high throughput screening is applied in nutrition research, it allows the examination of how nutrients affect the thousands of genes present in the animal genome. Nutrigenomics involves the characterization of gene products and the physiological function and interactions of these products. This includes how nutrients impact on the production and action of specific gene products and how these proteins in turn affect the response to nutrients. Nutrigenomics has been associated with the idea of personalized nutrition based on genotype. While there is hope that nutrigenomics will ultimately enable such personalised dietary advice, it is a science still in its infancy. Integration of genetic and metabolic studies using the zebrafish as a model affords an opportunity to dissect the fundamental pathways coordinating growth, nutrition and energy homeostasis. Goldsmith et al. (2006) revealed a critical transition in growth control during zebrafish caudal fin development.

Marine and aquatic biomass for energy production

Approximately 40 percent of all primary energy production, or photosynthesis, occurs in the seas. In this process, oceanic plants (phytoplankton, seaweeds, seagrasses) take up carbon dioxide and convert it into organic carbon (primarily sugars) and oxygen using light from the sun as an energy source. The oceans contain 50 times as much carbon dioxide as does the atmosphere, and it is estimated that primary production incorporates 35 gigatons of carbon into marine biomass annually. This abundant source of fuel for energy production has not been tapped commercially because it is not competitive with soybean meal and other easily harvested, traditional sources of biomass, and also because biomass is not presently competitive with other types of fuels, regardless of its source.

Among three strategic technologies being adopted in abroad, the first one , the enzyme that captures CO_2 for photosynthesis—ribulose bisphosphate carboxylase\oxygenase or “RUBISCO”—is relatively inefficient, so supercomputers are being used to verify structural information, and the enzyme is being redesigned to optimize its function. Second, the chemical composition of biomass can be altered to make it more suitable for particular applications. For example, marine microalgae are being genetically engineered to boost their lipid content, with the aim of providing a source of alternative fuels that is more economical than are conventional sources. Third, biotechnology is being used to convert biomass to ethanol and other alternative forms of energy and chemical feedstocks.

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Some technical and management aspects of catfish hatcheries in Hong Ngu district, Dong Thap province, Vietnam

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Dong Thap Province in the Mekong River Delta (in Vietnamese it means Delta of Nine Dragons) has a tropical climate and an abundant supply of fresh water the whole year-round. It borders Cambodia to the North, Vinh Long Province to the South, Long An and Tien Giang Provinces to the East; and Can Tho and An Giang to the West.

Dong Thap is also known as one of the provinces where the tra catfish, *Pangasianodon hypophthalmus*, aquaculture industry is well established. In 2006, the province produced 300,000 tonnes of catfish, contributing 37.5 % to the total production of Vietnam catfish aquaculture production. Catfish aquaculture in the province also employs about 40,000 people, out of the 1.6 million people who are living there.

Since the breakthrough in artificial propagation of catfish species in 1996, many farmers in Hong Ngu district of Dong Thap have changed from traditional rice cultivation to catfish breeding and culture. This change has significantly improved the income of farmers over the years. Statistics for 2007 show that the province has 87 catfish hatcheries, producing more than 4.4 billion larvae per year. Together with its neighbouring province of An Giang, Dong Thap is considered an epicenter of catfish seed supply for the whole Delta. In this article, we report some technical and economical aspects of 30 hatcheries in Hong Ngu district of Dong Thap province, based on a survey undertaken between July to September 2006.

General characteristics of hatcheries

All surveyed hatcheries were built after 1999. It is usual that owners also act as the chief technicians, and their level of education varied, with 80% having high-school certificate or higher, and with an age range of 31 to 60 years old. The majority of chief technicians (73.3%) gained their expertise through training courses, while 13.3% gained their experience through university degree, and the rest (13.3%) learnt from other hatcheries. There are often three to six persons working in a hatchery, who tend to be mostly family members and one to two persons from outside, usually neighbours.

Hatchery areas ranged from 0.2 to 3.0 ha, about 40% of which is used as broodstock ponds. Hatcheries maintain on average about 1,700 brood fish (about 4 kg each) with capacity to produce about 200 million fry per year. However, not all broodstock are used every year. For example, only 26% of broodstock was used to spawn in 2005. Hatcheries kept about 4% of fry and rear to fingerling, and the rest was sold to secondary hatcheries or nurseries for fingerling rearing and subsequently sold to grow-out farmers. The price of fry and fingerlings have significantly declined over the years, from about 52 VND and 532 VND, respectively in 2001, to 1 VND and 106 VND in 2005 (1US$ = 15,800 VND in 2005). Relevant information on hatchery production is given in Table 1.

Broodstock management, breeding and seed quality

The origin of broodstock varies between hatcheries. About 43% of hatcheries obtained wild-caught broodstock, 30% have only broodstock from hatchery origin, and the rest have a combination of both hatchery-produced and wild-caught