Regional Review on Existing Major Mariculture Species and Farming Technologies

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Introduction

For the purposes of this review, ‘mariculture’ is regarded as aquaculture of aquatic plants and animals that is undertaken in the sea. It thus excludes coastal aquaculture, particularly pond culture. But because much pond production is classified as ‘mariculture’ in the FAO statistics, it is difficult to get an accurate estimate of mariculture production in the Asia-Pacific region.

Taking the FAO data at face value, mariculture production in the Asia-Pacific region has grown from around 14.6 million tonnes in 1995 to around 26 million tonnes in 2003 (Table 1). Total value was in excess of US$21 billion in 2003.

Table 1 Aquaculture production and 2003 value for mariculture in the Asia-Pacific region. FAO data for Asia and Oceania, all species, all areas, mariculture only (FAO 2005b).

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	Value (US$m)
Australia	11,986	13,026	14,023	12,361	14,282	14,442	16,202	16,623	16,274	111
Bahrain	4	3	<0.5	1	3	12	<0.5	3	3	0
Cambodia	731	600	266	197	62	20	3,643	3,703	7,890	2
China	10,532,257	11,130,139	11,560,831	13,709,720	15,653,607	17,056,852	17,955,781	19,251,707	20,400,270	15,296
China, Hong Kong SAR	3,114	3,318	3,310	1,539	1,552	2,172	3,078	2,313	2,742	20
Cyprus	354	682	864	1,078	1,356	1,800	1,800	1,782	1,731	11
Fiji Islands	<0.5	<0.5	<0.5	210	2,925	1,936	1,736	80	25	0
French Polynesia	16	24	52	51	46	51	63	57	57	1
Guam	20	22	22	22	25	25	25	25	.	.
India	8	9	38	212	1,253	1,253	1,253	.	.	.
Indonesia	102,000	148,000	115,000	117,210	135,969	207,814	221,010	234,857	249,225	120
Israel	930	699	1,593	1,902	2,408	2,914	3,161	3,056	3,359	18
Japan	1,314,490	1,276,380	1,272,630	1,226,789	1,252,719	1,230,753	1,255,336	1,333,051	1,277,085	3,947
Kiribati	5,248	9,480	7,376	5,938	9,396	11,174	9,264	4,248	3,904	0
Korea, DPRep	732,917	779,421	485,791	478,000	478,000	464,000	504,295	504,295	504,295	283
Korea, Republic of	996,889	874,797	1,015,334	776,631	766,182	654,440	655,852	781,519	826,245	979
Kuwait	90	90	154	150	176	346	179	179	179	1
Malaysia	101,080	73,002	60,306	82,841	101,721	91,822	96,823	103,617	97,896	18
FSM	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Myanmar	1,143	1,796	2,123	2,392	4,936	4,964	5,473	6,550	19,181	77
New Caledonia	939	1,061	1,152	1,596	1,850	1,761	1,887	1,911	1,775	14
New Zealand	70,191	74,600	76,700	93,500	91,350	85,185	75,387	86,583	84,642	247
Oman	0	0	0	13	<0.5	<0.5	<0.5	<0.5	344	2
Pakistan	48	57	64	69	76	85	.	72	69	0
Palau	3	2	2	1	1	2	2	4	4	0

Philippines	605,864	691,193	683,343	722,009	735,537	747,414	828,670	936,853	1,039,083	92
Qatar	0	1	2	<0.5	<0.5	<0.5	1	<0.5	<0.5	<0.5
Samoa	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Saudi Arabia	201	201	830	1,758	1,898	2,003	4,212	4,695	9,209	69
Singapore	3,554	3,459	3,942	3,304	3,393	4,397	3,702	4,304	4,371	7
Solomon Islands	13	13	13	13	13	15	15	.	.	
Taiwan Province of China	33,237	34,889	31,354	26,035	24,034	28,281	26,982	29,037	33,507	113
Thailand	92,833	80,183	66,408	106,155	158,247	147,972	145,300	145,300	145,200	39
Tonga	.	.	.	.	.	.	.	.	3	0
Turkey	8,494	15,241	18,150	23,410	25,230	35,646	29,730	26,868	39,726	181
Tuvalu	.	.	.	.	.	.	.	.	5	0
United Arab Emirates	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	2,300	7
Viet Nam	21,320	19,651	29,578	33,270	43,629	55,000	70,000	100,000	130,000	115
Total	**14,639,974**	**15,232,039**	**15,451,251**	**17,428,377**	**19,511,876**	**20,854,551**	**21,920,862**	**23,583,292**	**24,900,599**	**21,770**

Status of farming of selected species

This presentation provides an overview of mariculture in the Asia-Pacific region. A feature of mariculture in the region is that it is exceptionally biodiverse, particularly in comparison with European mariculture, which relies on large-scale production of relatively few species. Because of this, and the rapidly changing nature of mariculture development in the region, it is difficult to undertake a detailed review of mariculture production at the specific level. Numerous species and commodity group reviews have been undertaken in the past few years, and others are in preparation or nearing completion. In particular, the CABI Aquaculture Compendium and the FAO species profiles will provide useful summary data on the status of a range of farmed species. Rather than dealing at the specific level, this presentation seeks to assess some overall issues and constraints to the development of sustainable mariculture in the Asia-Pacific region.

Marine finfish

Marine finfish aquaculture is well established in the Asia-Pacific region and is growing rapidly. A wide range of species is cultivated, and the diversity of culture is also steadily increasing.

Japanese amberjack *Seriola quinqueradiata* makes up 17% of marine finfish production in Asia, with just under 160,000 tonnes produced in 2003 (FAO 2005b). Nearly all of this production comes from Japan, where production levels have been relatively stable at 140,000 – 170,000 tonnes per annum since the 1980s. Other carangids that are becoming popular for culture are the snub-nosed pompano *Trachinotus blochii,* and silver pomfret *Pampus argenteus*.

Seabreams are a mainstay of Asian finfish mariculture production, and a range of species are currently cultured. Barramundi or Asian seabass (*Lates calcarifer*) is cultured in both brackishwater and mariculture environments, though most production is from brackishwater. Global production has been relatively constant over the past 10 years at around 20,000 – 26,000 tonnes per annum, although production has decreased in Asia and increased in Australia over this time.

Grouper culture is expanding rapidly in Asia, driven by high prices in the live fish markets of Hong Kong and China, and the decreasing availability of wild-caught product due to overfishing (Sadovy *et al.* 2003).

Southern bluefin tuna (*Thunnus mccoyii*) is cultured in Australia using wild-caught juveniles. Although production of this species is relatively small (3,500 – 4,000 tonnes per annum in 2001 – 2003), it brings very high prices in the Japanese market and thus supports a highly lucrative local industry in South Australia (Ottolenghi *et al.* 2004). The 2003 production of 3,500 tonnes was valued at US$ 65 million (FAO 2005b).

Cobia (*Rachycentron canadum*) is a species that is engendering much interest for tropical marine finfish aquaculture. Most production currently comes from China and Taiwan Province of China, and totalled around 20,000 tonnes in 2003 (FAO 2005b). However, production of this fast-growing (to 6 kg in the first year) species is set to expand rapidly, not only in Asia, but also in the Americas. Cobia is set to become a global commodity, in the same way that salmon has become a global commodity in temperate aquaculture.

Milkfish (*Chanos chanos*) has a long tradition of aquaculture in the Philippines where it is an important food item. Indonesia is a major producer of seed, much of this coming from ‘backyard’ or small-scale hatcheries, but most of the milkfish produced in Indonesia are used for bait by the Japanese tuna fishery. There are traditions of milkfish culture in some Pacific Islands, including Kiribati, Nauru, Palau and the Cook Islands. Although most milkfish culture is undertaken in brackishwater ponds, there is increasing production from intensive mariculture cages where the fish are fed pellets or trash fish.

Seedstock production

Hatcheries are producing greater numbers and a wider range of marine finfish species, but the industry is still heavily reliant of capture of fingerlings for grow-out, particularly for species that are difficult or costly to raise in hatcheries such as grouper or Napoleon wrasse (Sadovy 2000, Estudillo and Duray 2003) or for which there is no established hatchery technology, such as tunas (Ottolenghi *et al.* 2004). In general, the availability of seed from wild sources is in decline through over-fishing and habitat destruction (Sadovy 2000, Ottolenghi *et al.* 2004). Consequently, there is a need to develop sustainable technologies for seed production, particularly hatchery production.

Hatcheries range in size and technology. In Asia, there has been considerable development of small-scale or backyard hatcheries that have only a couple of larval rearing tanks. These hatcheries use basic but effective techniques to produce large numbers of seedstock of a range of marine finfish species. Traditionally, much of their production has been of milkfish but production is diversifying to include more difficult to rear species such as groupers (Sim *et al.* 2005a).

At the other end of the spectrum are the large technology-dependent hatchery systems which have been developed in Australia and Japan. Much of the hatchery technology in use in Australia has been adopted from Europe, and modified to meet local conditions (Battaglene and Kolkovski 2005). A major focus in developing hatchery technology in Australia in particular is the need to reduce labour inputs because of high labour costs.

Taiwan Province of China has established itself as a major seedstock production centre for the Asia-Pacific region, with around 1,000 farms involved in producing fry and juvenile marine finfish (Kao 2004, Su 2005). Marine finfish production in Taiwan Province of China is typified by highly specialised production sectors: e.g. one farm may produce eggs from captive broodstock, a second will rear the eggs, a third may rear the juveniles through a nursery phase (to 3–6 cm TL) and a fourth will grow the fish to market size (Liao *et al.* 1994, Kao 2004).

Nursery

There is substantial mortality of juvenile seedstock captured from the wild (Estudillo and Duray 2003). Amongst hatchery-reared juveniles, cannibalism is a major cause of losses in many species. Transportation of fingerlings also results in losses (Ottolenghi *et al.* 2004).

Grow-out technology

Grow-out technology employed in the Asia-Pacific region ranges from small floating or fixed cages used by small family-run operations, to extremely large cages (15 × 15 × 15 m) used for amberjack grow-out in Japan or 30–50 m diameter circular cages used for southern bluefin tuna grow-out in Australia (Ottolenghi *et al.* 2004, Rimmer *et al.* 2004).

Much of the marine finfish aquaculture production in the Asia-Pacific region is from small to medium scale farms. Many farms use relatively simple technologies, with wooden or bamboo cages and plastic barrels or polystyrene blocks to provide buoyancy. However, Japan and Australia in particular use larger and more sophisticated cage systems. In Australia's case, these are based on European technologies.

The traditional Asian cage system is suited to sheltered inshore waters. As coastal sites have become increasingly crowded, several countries have begun to adopt cage designs that can withstand more open water. These offshore cages have been based on Japanese and European designs. The ability to site farms in more open water has opened up more coastal area for farming.

A major issue regarding the continued proliferation of marine finfish aquaculture in the Asia-Pacific region is the environmental impact of such operations. Although there is now a good understanding of the environmental impacts of cage aquaculture in temperate environments, there has been relatively little work done in tropical systems. This issue is discussed further below.

Crustaceans

Although there is substantial production of marine shrimps in the Asia-Pacific region, effectively all of this production is undertaken in coastal ponds and thus does not meet the definition of 'mariculture' given above. There has been some experimental culture of shrimp in cages in the Pacific (Y. Harache, pers. comm.), but this has not yet been commercially implemented. Similarly, most crab aquaculture is carried out in coastal ponds and does not meet the definition of mariculture used here.

Tropical spiny rock lobsters (Family Panuliridae), and particularly the ornate lobster *Panulirus ornatus*, are cultured in Southeast Asia, with the bulk of production in Vietnam and the Philippines. Lobster aquaculture in Vietnam produces about 1,500 tonnes valued at around US$40 million per annum (Tuan and Mao 2004).

Tropical spiny rock lobsters are cultured in cages. In Vietnam, fixed, floating and submerged net cages are used, the former in shallow sheltered areas where the cages can be fixed to the substrate. Submerged cages are mainly used for nursing juvenile lobsters and are located in shallow water. A feeding pipe allows feed to be dropped into the cage, and limits the depth at which this system can be used. Floating cages may be used in depths up to 20 m (Tuan and Mao 2004).

Seedstock is obtained from the wild. In Vietnam, coconut logs are drilled with holes to provide an artificial substrate for puerulus / juvenile settlement. Once settled, the juveniles are removed from the logs and placed in nursery cages.

Lobsters are fed exclusively on fresh fish and shellfish, using about 70% fish and 30% shellfish. Vietnamese farmers show a strong preference for lizardfish (*Saurida* spp.) as a feed item, and will pay a higher price for these fish. Juvenile lobsters are fed 3–4 times per day, with chopped fish. Larger lobsters are fed 1–2 times per day and fish is fed whole. The FCR for lobsters fed this diet (fresh weight basis) is around 17–30:1 (Arcenal 2004, Tuan and Mao 2004).

In the Philippines, the preferred size at stocking is 100–300 g, and it takes 6–15 months for the lobsters to grow to the optimum size of 0.8–1.3 kg (Arcenal 2004). Survival is around 90%, although stocking smaller lobsters (30–80 g) reduces survival to less than 50% (Arcenal 2004). In Vietnam, it takes 18–20 months to culture juveniles (1–2 g) to the preferred harvest size of about 1 kg (Tuan and Mao 2004).

Although *P. ornatus* is a hardy species, there have been several recorded diseases associated with the use of poor quality seedstock in Vietnam. These include the bacteria *Aeromonas hydrophyla* and *Proteus rettgeri,* the fungi *Fusarium solari* and *Lagenidium* sp. and the parasites *Baranus* spp, *Zoothariniu* and *Vortiella* (Tuan and Mao 2004).

Mariculture of tropical spiny rock lobster in Vietnam is highly profitable, yielding a profit margin of 50% (based on a farm-gate price of US$26.75 /kg). More than 4,000 farmers / households are involved in lobster farming in Vietnam, so it makes an important contribution to coastal communities where it is practised (Tuan and Mao 2004). In contrast, farm gate prices for lobster in the Philippines are much lower: US$12–15 per kg, which limits profitability (Arcenal 2004).

Because seedstock supply is limited, and likely to remain so in the short- to medium term, and demand remains strong, farming of tropical spiny rock lobsters is likely to remain highly profitable for the foreseeable future. To enhance the sustainability of the industry, there is a need to ensure that seedstock supplies from the wild are conserved to support this valuable mariculture sector. This may be done by setting up Marine Protected Areas specifically to conserve adult breeding stocks of lobsters.

In the medium to long term, it is necessary to develop hatchery production technology for seedstock for tropical spiny rock lobsters. There is currently considerable research effort on developing larval rearing technologies for tropical spiny rock lobsters in Southeast Asia and in Australia.

There is a need to develop less wasteful and less polluting diets to replace the use of fresh fish and shellfish. Other research priorities are to: develop improved cages designs, assess the environmental impacts of tropical spiny rock lobster culture, and the assess carrying capacity of coastal environments.

Molluscs

Bivalves

Bivalves are a major component of aquaculture production in the Asia-Pacific region. Much of this production is based on mussel culture, which is a high-volume low-value commodity. In the Asia-Pacific region, Thailand and the Philippines are large producers of farmed mussels (Mohan Joseph 1998, FAO 2005b), primarily the green mussel *Perna viridis* (Lucas 2003).

At the other end of the spectrum, there has been substantial production of pearl farming which produces an extremely low-volume but high-value product: cultured pearls.

Despite the fact that hatchery production technologies have been developed for many bivalves, most tropical bivalve culture still relies on collection of seedstock from the wild. Artificial settlement substrates such as bamboo poles, wooden stakes, coconut husks or lengths of frayed rope are used to collect bivalve spat at settlement. The spat may be transferred to other grow-out substrates ('relayed'), or cultured on the settlement substrate (Mohan Joseph 1998, Lucas 2003).

There are three major systems commonly used for bivalve culture (Mohan Joseph 1998, Lucas 2003):

1. Within-particulate substrates
   This system is used to culture substrate-inhabiting cockles, clams, etc. Predator-excluding devices, such as mesh covers or fences, may be used.
2. On or just above the bottom
   This culture system is commonly used for culture of bivalves that tolerate intertidal exposure, such as oysters and mussels. Rows of wooden or bamboo stakes are arranged horizontally or vertically. Bivalves may also be cultured on racks above the bottom in mesh boxes, mesh baskets, trays and horizontal wooden and asbestos-cement battens.
3. Surface or suspended culture
   Bivalves are often cultured on ropes or in containers, suspended from floating rafts or buoyant long-lines.

Management of the cultures involves thinning the bivalves where culture density is too high to support optimal growth and development, checking for and controlling predators, and controlling biofouling (Mohan Joseph 1998, Lucas 2003).

Tropical mussels grow to market size (about 5–7 cm shell length) in less than 1 year, and in many cases 6–7 months, after settlement. Production can reach 1,800 tonnes per hectare annually, but may be lower in some areas. With a cooked meat yield of around 20%, this is equivalent to 360 tonnes of cooked meat per hectare per year (Mohan Joseph 1998). In Asia, farmed mussels are generally sold as whole fresh product. Some product is simply processed, e.g. shucked and sold as fresh or frozen meat. There has been some development of longer-life products, including canned and pickled mussels (Mohan Joseph 1998).

China and Japan are the largest producers of cultured scallops, with the bulk of production being the yesso scallop *Pecten yessoensis* (Lucas 2003). Production in

2003 exceeded 1.1 million tonnes of yesso scallop (FAO 2005b). Preferred harvest size (> 10 cm shell length) is reached in 2–3 years (Lucas 2003).

Giant clams (Family Tridacnidae) have been cultured in many Pacific Island countries. Their relatively slow growth rates make tridacnid clams suitable only for extensive aquaculture or stock enhancement. Much of the tridacnid aquaculture production is sold to the marine ornamental market which provides higher and more rapid returns.

Pearl oysters are farmed in Japan, China, Australia, Indonesia and in several Pacific Island nations, notably French Polynesia and the Cook Islands. Pearl culture is technically intensive, particularly the process of inserting a nucleus to promote formation of a pearl. The period between nucleus insertion and harvest generally ranges between 9 months and 3 years. The quality of the pearl is related to the length of the culture period, but many insertions are unsuccessful, resulting in the death of the pearl oyster or ejection of the nucleus (Lucas 2003). Pearl oysters are usually grown out using suspended culture systems, usually suspended below rafts or on long-lines.

Because of their filter-feeding nature, and the environments in which they are grown, edible bivalves are subject to a range of human health concerns, including accumulation of heavy metals, retention of human health bacterial and viral pathogens, and accumulation of toxins responsible for a range of shellfish poisoning syndromes. One option to improve the product quality of bivalves is depuration, which is commonly practised with temperate mussels, but rarely in the tropics (Mohan Joseph 1998, Lucas 2003).

A major constraint to the development of tropical mussel culture is limited demand and low price (Mohan Joseph 1998, Lucas 2003). Although prices are higher in Australia and New Zealand, mussels are still relatively low-priced compared with other seafood commodities. The low economic value of mussels is compensated for by their ease of culture and high productivity (Lucas 2003). Bioeconomic evaluations of mussel culture in the Philippines indicated a low return on investment for mussel farming, although farming in Thailand and Malaysia compared favourably with other forms of aquaculture (Mohan Joseph 1998).

Sea cucumbers

The most commonly cultured sea cucumbers are the temperate Japanese sea cucumber *Apostichopus japonicus* and the tropical sandfish *Holothuria scabra* (Yanagisawa 1998). Aquaculture production of *H. scabra* is low, and is generally still in the experimental phase. However, there is substantial production of *A. japonicus* from both coastal aquaculture and mariculture in China and Japan. Chen (2004) estimated Chinese production of *A. japonicus* in 2003 at 6,335 tonnes of which 5,865 tonnes (93%) was from cultured production, and only 470 tonnes from the wild fishery.

Farming of *A. japonicus* is well established in northern China. Most production is from earthen ponds, but there is also some mariculture using sea cages on the substrate or suspended below rafts. The sea cucumbers are fed *Sargassum* and other macroalgae (Chen 2004, Renbo and Yuan 2004). In contrast, sea cucumber farming in southern China is only beginning and is likely to utilise the species *Holothuria scabra*, *H. nobilis* and *H. fuscogilva* (Chen 2004). In Japan, *A. japonicus* juveniles are stocked in coastal waters to replenish local stocks, or develop new harvest fisheries (Yanagisawa 1998).

In Indonesia, *H. scabra* is farmed in cages of 20×20 m or 40×20 m in shallow (0.75 – 1 m deep) coastal areas, or in coastal fish ponds (Tuwo 2004). Organic material (such as rice bran and animal dust) is added at 0.2–0.5 kg per m2 every two weeks (Tuwo 2004). *H. scabra* grow relatively slowly and it takes around 6 months to reach the preferred harvest weight of 200–250 g (Tuwo 2004). Seedstock supply is mostly from the wild, although there is some hatchery production of juveniles (Tuwo 2004).

Production technology

Seed production technology for several sea cucumber species is well established. In China, about 6–8 billion juvenile *A. japonicus* have been produced since the 1980s (Chen 2004), and in Japan 2.6 million seed were produced in 1994 (Yanagisawa 1998).

Techniques for production of *H. scabra* have been developed in India, Indonesia, the Solomon Island, New Caledonia, Vietnam and Australia (Purcell 2004). Tuwo (2004) identified difficulties in accessing suitable broodstock, and low rates of survival to juvenile, as constraints to hatchery production of *H. scabra* in Indonesia.

Sandfish require large areas for nursery and grow-out phases because growth rapidly becomes limited as density increases (Pitt and Nguyen 2004). For this reason, there has been considerable focus on their use for sea ranching (Purcell 2004).

Market

The demand for sea cucumber products, particularly from China, dramatically exceeds supply. Chen (2004) notes that this is because the Chinese view sea cucumber as having medicinal properties, as well as being a delicacy. This high level of demand has pushed the price of bêche-de-mer (*A. japonicus*) from RMB 500 per kg in the 1980s, to RMB 600–1,000 per kg during the 1990s, and to around RMB 3,000 (≈US$400) per kg in 2003.

Other invertebrates

Sponges

Sponge aquaculture is generating considerable interest in the research community, but commercial production of farmed sponges in the Asia-Pacific region is low. There is a small commercial farm in Pohnpei (Federated States of Micronesia) and several experimental operations in Australia, New Zealand and the Solomon Islands.

Sponge aquaculture is similar to seaweed culture in that sponges can be propagated vegetatively, and little infrastructure is necessary to establish farms. The harvested product (for bath sponges) can be dried and stored and does not require infrastructure such as refrigeration. Consequently, like seaweed culture, sponge culture may be ideal for remote communities, particularly in the Pacific.

However, the market acceptance and economic viability of commercial sponge farming has not yet been established. Further assessment of basic biological parameters, such as growth and survival, as well as development of marketing channels, is necessary before large-scale sponge aquaculture can be developed.

Corals

There has been some small-scale development of coral farming in the Pacific Islands. Both soft and hard corals have been cultured, primarily for the marine aquarium trade, although some hard corals are sold as curios or used for restoration of degraded areas on coral reefs.

Corals are propagated vegetatively. Small pieces of live coral are glued to bases, and these are placed on underwater 'tables' fitted with galvanised wire mesh. Growth is reportedly rapid, with aquarium corals reaching harvestable size in 3–12 months.

Because of the low level of capital investment needed, and the relatively simple propagation methods used, coral culture is suitable for remote coastal communities where infrastructure may be lacking.

Seaweeds

Aquatic plants are a major production component of mariculture in the Asia-Pacific region. About 13.5 million tonnes of aquatic plants were produced in 2003 (FAO 2005b). China is the largest producer, producing just under 10 million tonnes. The dominant cultured species is Japanese kelp *Laminaria japonica* (Lüning and Pang 2003, Tseng and Borowitzka 2003).

There are around 200 species of seaweed used worldwide, or which about 10 species are intensively cultivated, including the brown algae *L. japonica* and *Undaria pinnatifida*, the red algae *Porphyra*, *Eucheuma*, *Kappaphycus* and *Gracilaria*, and the green algae *Monostrema* and *Enteromorpha* (Lüning and Pang 2003).

Seaweeds are grown for:

- direct consumption, either as food or for medicinal purposes;
- production of the commercially valuable polysaccharides alginate and carrageenan;
- use as fertilisers;
- feed for other aquaculture commodities, such as abalone and sea urchins.

Production technology

Because cultured seaweeds reproduce vegetatively, seedstock is obtained from cuttings. Grow-out is undertaken using natural substrates, long-lines, rafts, nets, ponds or tanks (Tseng and Borowitzka 2003).

Production technology for seaweeds is inexpensive and requires only simple equipment. For this reason, seaweed culture is often undertaken in relatively undeveloped areas where infrastructure may limit the development of other aquaculture commodities, for example in Pacific Island atolls. Existing technologies rely on tying individual plants to lines are time-consuming and limit production (Ask and Azanza 2002).

Seaweeds are subject to a range of physiological and pathological diseases:
- 'green rot' and 'white rot' are caused by environmental conditions, particularly light levels (Tseng and Borowitzka 2003);
- 'ice-ice' disease in *Eucheuma* / *Kappaphycus* is associated with low light levels and reduced salinity (Ask and Azanza 2002);
- epiphytes compete with cultured seaweeds for nutrients, and may block light to the thalli (Ask and Azanza 2002, Lüning and Pang 2003);
- several pathogenic diseases are associated with infections of bacterial and mycoplasma-like organisms (Tseng and Borowitzka 2003).

In addition, cultured seaweeds are often consumed by herbivores, particularly sea urchins and herbivorous fish species such as rabbitfish (Family Siganidae) (Ask and Azanza 2002).

Selective breeding for specific traits has been undertaken in China to improve productivity, increase iodine content and increase thermal tolerance to better meet market demands. More recently, modern genetic manipulation techniques have been used to improve temperature tolerance, increase agar or carrageenan content and increase growth rates. Improved growth and environmental tolerance of cultured strains is generally regarded as a priority for improving production and value of cultured seaweeds in the future (Ask and Azanza 2002, Tseng and Borowitzka 2003).

Seaweed aquaculture is well-suited for small-scale operations, by 'grassroots' people running a seaweed business at a household level. Seaweed fisheries are traditionally the domain of women in many Pacific island countries, so it is a natural progression for women to be involved in seaweed farming. Seaweed farming in the Philippines is undertaken in areas where civil disturbance may occur, limiting production (Philippines country paper, these proceedings).

Priorities for R,D&E

Mariculture in the Asia-Pacific region is expanding rapidly, and there is widespread concern regarding its sustainability. Priorities for research, development and extension (R,D&E) should be focused on increasing the sustainability of mariculture production.

Seed supply

Seed supply for mariculture comes from two sources: wild populations, where larvae or juveniles are harvested to provide seedstock for grow-out (capture-based aquaculture) and hatchery production of seedstock.

Capture-based aquaculture

Capture-based aquaculture is widely practised in the Asia-Pacific region, and many seedstock fisheries may be drastically over-exploited (Sadovy 2000, Ottolenghi *et al.* 2004). In general, there is a need to move away from capture-based aquaculture to hatchery production to improve the sustainability of these aquaculture sectors.

R,D&E Priorities

- Improved knowledge of biology of relevant species and their fisheries.
- Develop specific policies and legal frameworks for capture-based aquaculture that promote interactions between the fishing and farming sectors.
- Spat-fall forecasting for molluscs.

Hatcheries

While hatchery production of seedstock is generally more sustainable than the use of wild seedstock, there remain a range of constraints to widespread adoption of hatchery production.

R,D&E priorities

- Need to develop seedstock production technologies to support a wider range of species, including species where seedstock is currently reliant on wild capture.
- Control and management of disease, particularly viral diseases.
- Promote small-scale hatchery technology to provide livelihood options for marine finfish aquaculture in coastal areas.
- Develop more cost-effective larval rearing techniques, such as the use of compounded larval feeds.
- New technologies for effective transport of seedstock (finfish fingerlings, bivalve spat) from hatcheries / nurseries to farms are needed.
- Development and promotion of specific-pathogen-free or high-health seedstock.

Genetics issues

Selective breeding has commenced with a wide range of maricultured species. However, the long-term impacts of selective breeding are not well established, particularly for mariculture systems where there is a high risk of selectively bred organisms escaping to interact with wild populations.

R,D&E priorities

- There are indications that inbreeding in some species has led to a decline in seedstock quality. Genetic management protocols are required for hatcheries to prevent inbreeding effects in captive populations.
- There is a need to develop selective breeding programs for a range of maricultured commodities. Some of the desirable selected traits include: disease resistance, high growth rate, increased thermal tolerance, product colour, and biochemical composition (e.g. carageenan content in seaweeds).
- There is a need to establish the biodiversity impacts of selectively-bred organisms contributing to wild populations.

Production systems

Production systems in many parts of the Asia-Pacific are relatively simple, and are ideally suited to small-scale or family aquaculture. However, the trend is for development of large-scale farms incorporating a range of technologies to improve the cost-efficiency of production. Marine finfish aquaculture in Asia is adopting the technologies used in Europe originally developed for large-scale salmon production. These systems are likely to be more cost-effective for some species (such as cobia) than for others (groupers). However, there is also a need to improve production systems for mollusc and seaweed culture.

Feeds

So-called ‘trash’ fish (small, low-value or bycatch fish species) are a major source of feed inputs in aquaculture in the Asia-Pacific region. The term ‘trash’ fish is inaccurate in that these fish species would not necessarily otherwise be wasted, and alternative uses include reduction to fish sauce for human consumption, protein sources for other agricultural commodities (such as pigs and poultry) or even direct human consumption (New 1996, Tacon and Barg 1998, Edwards *et al.* 2004, FAO 2005a).

The issues associated with ‘trash’ fish usage are well documented, most recently in the report of the ‘APFIC Regional Workshop on Low Value and ‘Trash Fish’ in the Asia-Pacific Region’ (FAO 2005a). Although pellet diets are available for a range of marine finfish as well as some crustaceans, there remain important constraints to the widespread use of compounded diets for aquaculture:

- Farmer acceptance of pellet diets is often low because of the perception that these diets are much more expensive than trash fish. Farmers often do not appreciate that the food conversion ratios of pellet diets (usually 1.2–1.8:1) is dramatically better than that of ‘trash’ fish (usually 5–10:1, but sometimes higher) and so the relative cost of pellet diets is often comparable, or lower than, the cost of trash fish required to produce the same biomass of fish.
- Variable product quality may also impact substantially on growth and survival of the cultured fish.
- Lack of farmer experience in feeding pellets may result in considerable wastage.
- Fish fed on ‘trash’ fish may not readily convert to a dry pellet diet, resulting in poor acceptance and perceived lack of appetite.
- Distribution channels for pelleted feed are not widely available in rural areas. As well as limiting accessibility to the feed, this factor increases the cost of the feed.

- Many rural areas have no storage facilities, and this can result in degradation of the pellets, particularly vitamin content, resulting in poor growth and disease in fed fish.
- Small-scale fishers or farmers operating fish cages may not have access to the financial resources necessary to invest in purchase of pelleted diets or infrastructure such as refrigeration, finding it easier to collect 'trash' fish themselves, or in small amounts as and when financial or 'trash' fish resources are available. For many farmers, 'trash' fish collection is an opportunity cost which in family-operated farms may be easily absorbed, whereas the purchase of pellets is a cash cost.

R,D&E priorities

- The nutritional requirements of aquacultured species have to be determined in order to develop cost-effective diets. Research has demonstrated that different aquacultured species often have different nutritional requirements. Consequently, there will be a range of diets required for various species or species groups. There is a need to define the nutritional requirements of aquacultured species, often at the generic or even specific level.
- There is a need for R&D into alternative protein sources for aquafeeds, including terrestrial meat meals and vegetable meals to replace fish protein.
- Changing from 'trash' fish to pellet feeds may impact on product quality. The real and perceived impacts of compounded feeds on product taste and texture need to be established in view of consumer preferences. For some species, this may not be important, but this is an issue for high-value marine finfish, e.g. groupers.
- Enhanced information exchange and coordination of nutritional information would benefit the development of compounded aquafeeds.
- Participatory research and extension is a valuable mechanism for promoting the uptake of compounded feeds. The various drivers towards / away from pellet feeds need to be better understood and documented.
- There is a need for feed companies to become actively involved in on-farm trials and to independently evaluate their products. There is no doubt that some batches of pellets perform poorly due to problems with formulation, manufacture, or storage. There is a need to work with feed companies to improve product quality and identify areas where improvements can be made.
- National aquaculture development strategies need to incorporate a policy for feeds development.
- There is a need to better quantify the environmental impacts of both 'trash' fish and pellet feeds both in terms of nutrient impacts, as well as particulate matter that may cause impacts to benthic communities beneath sea cages. The impacts of feed type need to be integrated with aquaculture planning, farm siting and coastal management.

Environmental impacts of mariculture

Although mariculture production in the Asia-Pacific region includes a substantial quantity of low-trophic-level species, such as seaweed and bivalve molluscs, there is a significant production of commodities that require feed inputs; in particular, crustaceans (lobsters) and marine finfish. Environmental impacts associated with marine finfish and lobster cage aquaculture derive mainly from nutrient inputs from uneaten fish feed and fish wastes (Phillips 1998). For example, studies carried out in Hong Kong indicate that 85% of phosphorus, 80–88% of carbon and 52–95% of nitrogen inputs (from 'trash' fish) to marine finfish cages may be lost through uneaten food, faecal and urinary wastes (Wu 1995). These nutrient inputs, although small in comparison with other coastal discharges, may lead to localised water quality degradation and sediment accumulation. In severe cases, this 'self pollution' can lead to cage farms exceeding the capacity of the local environment to provide inputs (such as dissolved oxygen) and assimilate wastes, contributing to fish disease outbreaks and undermining sustainability.

However, the impacts of sea cage aquaculture on coastal waters may be relatively insignificant compared with the terrestrial inputs. In one of the few studies of nutrient impacts of marine cage aquaculture in tropical systems, Alongi *et al*. (2003) found that although fish cages theoretically contributed 32–26% of nitrogen and 83–99% of phosphorus to the coastal water studied, there was no evidence of large-scale eutrophication due to the cages, and the effects of the cages was largely swamped by large inputs of organic matter from mangrove forests, fishing villages, fish cages, pig farms and other industries within the catchment.

The use of dry pellets rather than wet feeds reduces nutrient inputs through better feed utilisation. Other solutions to self-pollution of sea cage sites (Phillips 1998, Feng *et al.* 2004) are:

- ensure adoption of 'Better / Best Management Practices', including efficient feed formulation and feeding practices,
- keep stocking densities and cage numbers within the carrying capacity of the local environment,
- minimal and responsible use of chemicals,
- ensure adequate water depth below cages and sufficient water movement to disperse wastes, and
- moving cages regularly to allow recovery of the sediments of affected sites.

There is increasing appreciation of the environmental impacts of mariculture in Southeast Asia, partly because of the worldwide focus on the environmental impacts of Atlantic salmon farming. However, in most countries there is a lack of legislative frameworks and enforcement. Problems can be addressed by more emphasis on local planning initiatives and co-management frameworks, and zoning of coastal areas for marine fish farming. Hong Kong provides one example where the government has designated marine fish farming zones, however critics argue that zoning has allowed too much crowding and localised water pollution (Lai 2002, Sadovy and Lau 2002). Therefore, zoning of marine fish farming areas has to be accompanied by control measures that limit farm numbers (or fish output, or feed inputs) to ensure effluent loads remain within the capacity of the environment to assimilate wastes (Phillips 1998).

The Philippines is establishing mariculture parks to promote finfish mariculture within a designated area. The park development is controlled by an Executive Management Council that governs the establishment of 'community' mooring systems and clusters of sea cages. This approach attempts to limit uncontrolled development of sea cages, and limit expansion, encroachment and interference with other marine infrastructure (Philippines country paper, these proceedings).

R,D&E priorities

- Need for appropriate environmental assessment systems to support site selection and assess the assimilative capacity of the local environment.
- Implementation of aquaculture planning and development, taking into account other resource users.
- Development and enforcement of regulations that limit aquaculture development within appropriate levels, and ensure environmental monitoring is carried out.
- Development of robust and cost-effective environmental monitoring systems appropriate to tropical mariculture.
- Improved knowledge of the role of wild fish communities as potential disease vectors, and as sinks for excess feed and wastes.
- Fate and impacts of antibiotics and other pharmaceuticals.

Post-production

Both the supply of, and demand for, aquatic products are changing rapidly in the Asia-Pacific region. While fisheries production is relatively stable, aquaculture production is increasing steadily. The region contains the two largest national populations on the planet: China and India. Demand for quality seafood products is expanding in line with growth in affluence in many parts of Asia. In the light of this rapidly changing environment, the ability to match supply and demand in terms of both quantity and quality of products is critical.

R,D&E priorities

- Improved harvesting and handling techniques to improve product quality.
- Post-harvest handling and processing, and food safety, including depuration for bivalves.
- Development of new products – 'value adding'.
- Development of new market strategies and new market segments.
- Improved market intelligence, particularly to allow farmers to diversify or change production strategies.

Socio-economic

The country papers presented at this meeting provide information on the extent of the importance of both coastal aquaculture and mariculture to coastal communities throughout the Asia-Pacific region. However, there is still limited information on how coastal communities will respond to changes in mariculture production trends, such as the trend away from low-input commodities (e.g. seaweeds) to more intensive farming systems (e.g. finfish) in China.

R,D&E priorities

- Better information on the socio-economic impacts of mariculture on coastal communities, both positive and negative.
- The role of mariculture in alleviating poverty in developing countries.

- The impacts of 'urban drift' in rapidly developing economies – many younger people are looking for employment opportunities in the cities rather than taking traditional roles in sectors such as fisheries and aquaculture (Korea country paper, these proceedings).

Potential for increasing the role of low-trophic-level species

There is interest in promoting the cultivation of low-trophic-level marine species to alleviate some of the impacts of culturing animals that require high levels of organic inputs, such as marine finfish. There are two approaches to promoting the cultivation of low-trophic-level species:

1. Direct replacement of high-input species with low-input species, e.g. replacing production of carnivorous finfish (groupers, etc.) with omnivorous species (e.g. milkfish, rabbitfish);
2. Promotion of low-trophic-level species that may act as 'sinks' for the waste products from high-input aquaculture.

Direct commodity substitution with low-trophic-level species

As noted above, there is already substantial mariculture production of low-trophic-level species in the Asia-Pacific region. Low-trophic-level species include bivalve molluscs, sea cucumbers and seaweeds. Amongst marine finfish, both milkfish and rabbitfish can be considered low-trophic-level species. Milkfish are cultured throughout the Asia-Pacific region, though most production is from the Philippines and Indonesia, and most of this production is from coastal ponds rather than from mariculture. Rabbitfish are cultured only is small quantities.

One of the drivers against adoption of low-trophic-level species in mariculture is price. Many low-trophic-level species are relatively low-price commodities, the notable exception being sea cucumbers. In China, production of seaweeds has proportionally declined since 1981 because of proportionally greater production of molluscs, shrimps and finfish (Feng *et al.* 2004). The major reason for this shift is that animal cultivation is more profitable (Feng *et al.* 2004).

Economic drivers may be important for farmers choosing which species to cultivate. Yap (2002) found that grouper aquaculture in the Philippines was more accessible to farmers than milkfish culture because of higher margins and the lower level of investment required to achieve the same profit.

Cultivation of low-trophic-level species may not necessarily result in environmental benefits. For example, while milkfish can be farmed extensively with negligible feed inputs, this type of culture is generally being replaced with more intensive styles of culture. Cage culture of milkfish relies on the same high levels of inputs as does any other type of marine finfish aquaculture, albeit with lower protein feeds and thus likely lower nitrogen inputs to the environment. The localised environmental impacts from large-scale milkfish culture do not differ substantially from any those of any other marine finfish production.

Promotion of low-trophic-level species as nutrient sinks

Many authors have suggested that one solution to high levels of nitrogen inputs from aquaculture is to culture organisms that act as nitrogen sinks, particularly seaweeds (Chopin *et al.* 2001a, Feng *et al.* 2004). Most work to date, however, has focused on the use of seaweeds as nutrient sinks in land-based systems (Chopin *et al.* 2001b, Neori *et al.* 2004).

Feng *et al*. (2004) noted that 50 tonnes of seaweed can fix 1,250 kg of carbon and 125 kg of nitrogen. Using Wu's (1995) data on finfish effluent fed a diet of 'trash' fish and an FCR of 8:1, the nitrogen produced from <u>1 kg</u> of marine finfish production (4.2–7.6 kg N) would require the absorptive capacity of <u>1.7–3.0 tonnes</u> of seaweed production. Given the economic drivers away from seaweed production towards more profitable commodities, it is difficult to envisage that large-scale mariculture will incorporate seaweed production at an order of magnitude greater than finfish production.

The dynamic processes that affect utilisation of nutrients in tropical mariculture are poorly researched. It is likely that much of the soluble waste from aquaculture production is used up rapidly by bacteria and phytoplankton, and high nutrient levels may not persist far from their source. In this case, there may be limited additional nutrients available for seaweed culture.

An alternative is the use of intermediate organisms to remove phytoplankton that may proliferate because of the nutrient-rich environment adjacent to cages. Pham *et al.* (2004) describe co-culture of green mussels (*Perna viridis*) with tropical rock lobster. Lobsters fed the mussels demonstrated faster growth and better health than those fed 'trash' fish. Water quality around cages where mussels were co-cultured with lobsters had reduced concentrations of organic matter in the water column and in the sediment (Pham *et al.* 2004). The use of filter-feeding bivalves as a nutrient sink which can then be used as a feed source for other cultured species, is a potentially valuable option to improve the sustainability of mariculture.

Integrated Mariculture

The widespread recognition that aquaculture must improve its environmental performance, both real and perceived, has generated interest in integrated aquaculture. Integrated aquaculture is broadly defined as the culture of a range of trophic-level organisms whereby outputs from one species or group can be utilised as inputs by another species or group. While there has been some research undertaken using land-based systems (Chopin *et al.* 2001a, Chopin *et al.* 2001b, Neori *et al.* 2003, Troell *et al.* 2003, Neori *et al.* 2004) there has been comparatively little research on 'open' or mariculture systems.

While the concept of integrated mariculture is straightforward, there is a paucity of information to assess its effects on the environment. The dynamics of aquaculture-generated nutrients in tropical coastal waters are complex and not well understood. Because much of the nutrient input may be absorbed rapidly by phytoplankton and bacteria, the systems used for integrated mariculture may differ substantially from those used in land-based systems, which rely on aquatic plants as nutrient sinks (Neori *et al.* 2004). With the rapid expansion of mariculture in the Asia-Pacific region, and the need to improve the environmental credentials of mariculture, the topic of environmental impacts and the development of cost-effective amelioration strategies is a high priority.

Better Management Practices for mariculture

An approach to improving the sustainability of aquaculture has been the development of Better Management Practices (BMPs). To date, BMPs have been most widely used in coastal aquaculture, particularly shrimp culture. More recently, the development of BMPs for mariculture has commenced, particularly with regard to tropical marine finfish aquaculture. The Marine Aquarium Council, together with The Nature Conservancy and with the assistance of NACA, has developed Standards for the Live Reef Food Fish Trade, including aquaculture standards. These standards provide a basis for the development of BMP documentation for finfish mariculture.

Two recent publications from the Asia-Pacific Marine Finfish Aquaculture Network demonstrate the BMP approach to finfish mariculture with respect to promotion of small-scale marine finfish hatchery technology (Sim *et al.* 2005a) and the use of compounded feeds instead of 'trash' fish to feed groupers (Sim *et al.* 2005b). These publications are being made widely available in the Asia-Pacific region, and have been translated into Thai, Indonesian and Vietnamese to facilitate farmer access to this information. APMFAN plans to expand its range of BMP documentation in future years.

Adoption of BMPs, particularly voluntary adoption, remains problematic. While some BMPs may improve the financial viability of farms, for example through more cost-effective feeds, faster fish growth and improved fish health (Sim *et al.* 2005b), other BMPs may have associated financial costs that farmers are reluctant to bear (Stanley 2000). Another issue with regard to adoption of BMPs for mariculture, as noted above, is the paucity of information on the nutrient dynamic processes associated with tropical mariculture. In the absence of detailed research results, it is difficult to develop detailed BMPs, particularly if there are financial costs involved in their adoption.

Different countries in the Asia-Pacific region have BMP or BMP-like information available in a variety of forms. In Australia, there are Codes of Practice for several industry sub-sectors, including a Harvesting and Processing Code of Practice for barramundi farmers. In the Republic of Korea, the National Fisheries Research and Development Institute publishes culture standards for each aquaculture species (Korea country paper, these proceedings). Information sharing amongst farmers is supported by the installation of internet-connected computers in the homes of fish farmers in 100 model fishing villages. Fishermen have access to various information sources, including the ability to communicate through a specialised web site (www.badaro21.net) (Korea country paper, these proceedings).

A useful approach would be the development of BMPs, including the coordination and redistribution of existing information, at a regional level. Most of the issues facing mariculture in the Asia-Pacific region are not country-specific, so a coordinated approach would provide consistency and reduce duplication of effort. As the regional organisation with responsibility for coordination of aquaculture activities, NACA is ideally placed to direct this coordinated effort.

Regional Resource Centres and Experts

Note: this is a provisional list only. Identification of additional resources would be welcomed by the author.

India

Indian Council of Agricultural Research

Central Marine Fisheries Research Institute; Kochi

Marine Products Export Development Authority

Rajiv Ghandi Centre for Aquaculture; Chennai, Port Blair

Indonesia

Directorate-General of Aquaculture, Technical Implementation Units

1. Centre For Marine Aquaculture Development, Lampung (Sumatera)
2. Marine Aquaculture Development Centre, Batam (Riau)
3. Marin Aquaculture Development Centre, Ambon
4. Marin Aquaculture Development Centre, Lombok (West Nusa Tenggara)
5. Centre for Brackish Water Aquaculture Development Centre, Jepara (Central Java)
6. Brackish Water Aquaculture Development Centre Takalar (South Sulawesi)
7. Brackish Water Aquaculture Development Centre, Situbondo (East Java)
8. Brackish water Aquaculture Development Centre, Aceh

The role of the TIUs is to conduct technology propagation/ extension, and develop applied technology. So they are equipped with: commercial scale experiment facility (hatchery, nursery, and grow out facility) training facility, dormitory, and laboratory services.

The technology transfer by these institutions includes:

a) On the job training. The participants stay, learn, and work with the staff in charge for certain period depend on the subject and level
b) Poster and leaflet publication
c) Supervising on farm
d) Pilot project, prototype, modelling

Central Research Institute for Aquaculture

1. Gondol Research Institute for Mariculture (Bali)
2. Research Institute for Coastal Aquaculture, Maros (Southern Sulawesi)

Iran

The Iranian Fisheries Research and training Organization www.fro.org affiliated to Shilat is the major source of applied research and training on fisheries and aquaculture. It has 10 research centres and two training centres:

- Four centres are located by the Persian Gulf and Oman Sea: Khuzestan, Bushehr, Hormozgan and Sistan –Baluchestan provinces;

- Five Fisheries Research Centres are located by the Caspian Sea: Giulan, Mazandaran and Golestan provinces, International Institute of Cold Water in Mazandaran and International Institute of Sturgeon in Giulan.
- Artemia Research Centre located by the Urmia Lake (works on *Artemia* and live feed)

Research outcomes are used for running pilot projects and modification. The results are then extended to farmers trough short training courses and manuals.

Republic of Korea

Eighteen fisheries subsidiary organizations, including several branch offices of the Ministry of Maritime Affairs and Fisheries (MOMAF) exist in rural areas, mostly located along the coastal areas. The role of the organizations is to support fishermen with information, training and government funding. The major government aquaculture research institutes are the National Fisheries Research Development Institute (NFRDI) and Pukyong National University

Vietnam

Research Institute for Aquaculture No.1, Cua Lo and Cat Ba
Research Institute for Aquaculture No.2, Ho Chi Minh City and Vung Tao
Research Institute for Aquaculture No.3, Nha Trang
University of Fisheries, Nha Trang
Institute of Oceanography, Nha Trang

Malaysia

- Institute of Marine Aquaculture (IAM), Pulau Sayak, Kedah, which opened in 1987. Among the courses offered at the centre are marine finfish seed production, finfish aquaculture in cages, marine shrimp seed and grow out program, seed and grow out production of oyster and mussel and feed formulation for farm practice.

- Marine Finfish Production and Research Centre (MFPRC) Tanjung Demong, Besut, Terangganu located at the east coast of peninsular Malaysia. At MFPRC courses are offered on marine finfish fry production and cage culture operation.

Additional resources

FAO species profiles
www.fao.org/figis/servlet/static?dom=root&xml=aquaculture/cultured_search.xml

CABI Aquaculture Compendium
www.cabi.org/compendia/ac/

Secretariat of the Pacific Community Aquaculture Commodity Profiles
www.spc.int

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