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Development of mariculture and its impacts in Chinese coastal waters

Yang Yu Feng[1], Li Chun Hou[2], Nie Xiang Ping[1], Tang Dan Ling[3,1] & Chung Ik Kyo[4]
[1]*Institute of Hydrobiology, Jinan University, Guangzhou 510632, P.R. China (Phone: +86-20-85220239; Fax: +86-20-85220239; E-mail: tyyf@jnu.edu.cn);* [2]*South China Sea Fishery Research Institute, Chinese Academy of Fishery Sciences, Guangzhou 510300, P.R. China;* [3]*LED, South China Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, P.R. China;* [4]*Department of Marine Science, Pusan National University, Busan 609-735, Korea*

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Contents

Key words: China, environmental impacts, fisheries management, mariculture development, seaweed cultivation

Abstract

China has a long history of aquaculture. Since the 1980s, mariculture has been considered by the government as an increasingly important sub-sector of aquaculture. Mariculture provides nutritional and economic benefits, and decreases the intensity of exploitation on declining wild living resources. China now has the highest mariculture production in the world. Kelp made up 50–60% the total Chinese mariculture production in 1967–1980. Production of *Laminaria japonica* Aresch, the leading species, reached 252, 907 t (dry wet) in 1980. The percentage of kelp production decreased after 1981 because of proportionally greater production of molluscs, shrimps and finfish. Marine finfish and mollusc production increased sharply after 1990. In 2001, the total mariculture production reached 11,315,000 t from a production area of 1,286,000 ha. The rapid development and changes in mariculture species have aroused increasing concern about mariculture's impact on the coastal environment. The impact of coastal aquaculture, such as water quality deterioration and contaminants, will have a significant bearing on the expansion of mariculture. The key of improving and maintaining the long-term health of mariculture zones lies in adopting sustainable culture systems. It is imperative that the density of stocking fish and other economically important organisms such as oysters, and scallops, be controlled, in addition to restricting the total number of net-cages in the mariculture zones. The authors suggest moving rafts (cages) periodically and to development of a fallow system in which area fish culture will be suspended for 1–2 years to facilitate recovery of the polluted sediment. Moving fish culture offshore into deeper waters is also suggested. The authors also believe that large-scale seaweed cultivation will reduce eutrophication in coastal culture zones in China.

Table 1. The principal mariculture species in Chinese costal waters

Fish: *Sparus macrocepalus* Basilewsky, *Pagrosomus major* Temminck et Schlegel, *Plectorhynchus cinctus* Temminck et Schlegel, *Pseudosciaena crocea* Richardson, *Mugil cephalus* Linnaeus, *Rachycentron canadum* Linnaeus, *Lateolabrax japonicus* Cuvier et Valenciennes, *Sebastes schlegeli* Hilgendorf, *Paralichthys olivaceus* Temminck et Schlegel, *Pneumatophorus japonicus* Houttuyn

Shellfish: *Mytilus edulis* Lamarck, *Perna viridis* Linnaeus, *Tegillarca granosa* Linnaeus, *Ruditapes philippinarum* Adams et Reeve, *Chlamys farreri* Jones et Preston, *Crassostrea gigas* Thunberg, *Saccostrea cucullata* Born

Shrimp: *Penaeus orientalis* Kishinouye, *P. japonicus* Bate

Crab: *Scylla serrata* Forskal, *Portunus trituberculatus* Miers

Macroalgae: *Laminaria japonica* Aresch, *Porphyry haitanensis* Chang et Zhang, *P. yezoensis* Ueda, *Gracilaria lemaneiformis* (Bory) Daws, *Undaria pinnatifida* (Harv.) Suringar, *Gelidium amansii* (Lamx.) Lamx.

Introduction

China is the world's largest country with a population of some 1300 million; it has a long history of aquaculture. But the amount of land resources is inadequate to meet the increasing demand for animal protein. Since 1980s, aquaculture has been considered by the government as an increasing important sub-sector that provides nutrition and economic benefits to the country on the one hand, and reduces the exploitation of declining wild living resources on the other hand. China has had the highest mariculture production in the world since the late 1980s (Qian, 1994; Fang et al., 2001). According to data from the China marine statistical yearbook, the total mariculture production reached 11,315,000 t from a production area 1,286,000 ha in 2001 (SOA, 2002). But mariculture operations may have a considerable impacts on the coastal environment. With the strengthening of the peoples' sense of environmental protection, ecological effects and management of the mariculture zones have become a growing concern. Fisheries management in the mariculture zones is no longer merely questions of maximizing the yields and economic benefits, it has become important to consider the direct and indirect impacts of mariculture on other components of the culture ecosystem in the overall management strategy.

Mariculture development

Mariculture systems in China usually operate in coastal waters at depths less than 15 m in intertidal mudflats, shallow seas and bays, but recently, mariculture areas have expanded to depths up to 50 m. The principal mariculture groups include shellfish, fish, shrimp, crab and seaweeds in cages, on rafts or in sea water ponds (Table 1) (Gan et al., 2000; Liu and Liu, 2001).

According to data from SOA (2002) and the China statistical yearbook of aquatic production 1999, Fisheries Bureau, Ministry of Agriculture, Chinese mariculture production increased from year-to-year during 1961–2001 (Figure 1). Annual production was less than 800,000 t during the 1960s–1970s. From the mid-1980s to the present, intensive mariculture activities increased to meet the demand for aquatic products. The annual production was 1,246,500 t in 1985, 7,215,100 t in 1995, and 11,315,000 t in 2001. The production of 2001 was 71 times of 1961, and 9.1 times of 1985 production.

In 1967–1980, 50–60% of the total Chinese mariculture production was kelp. Production of *Laminaria japonica* ranked first, and reached 252,907 t (dry wet) in 1980. The proportional production by kelp decreased somewhat after 1981 because of an increase in the production of molluscs, shrimps and finfish. Marine finfish and mollusc production has increased sharply since 1990, accounting for 1 and 17%, respectively, of

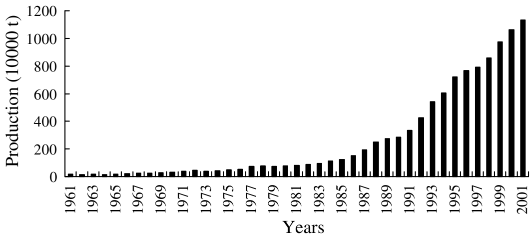

Figure 1. Long-term changes in mariculture production in Chinese coastal waters.

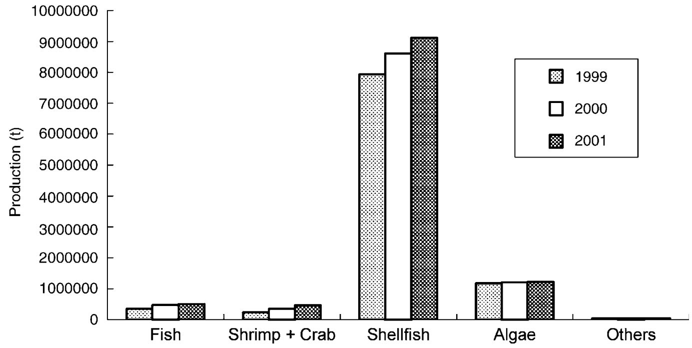

Figure 2. Mariculture production (t) in Chinese coastal waters during 1999–2001. Data sourced from SOA (2002).

total aquaculture production in 1995. Production of crustaceans, mainly Chinese shrimp (*Penaeus orientalis*) increased up to 1991 and then fell due to disease-related problems and sub-optimal management. Now farms engaged in raising fish, shrimp, crab and shellfish do better jobs of management and receive better dividends (Tseng and Fei, 1987; Qian et al., 2001). The cage cultivation industry of marine fish started to operate in China in the 1970s, and now, there are more than 1 million cages used along Chinese coastal waters, most are in Guangdong (> 300,000), Fujian (600,000–700,000), Zhejiang (75,000), Shandong (20,000) and other coastal regions. Animal cultivation has become an important economic pillar of the Chinese mariculture industry.

The annual production of shellfish reached 7,934,771 t (1999), 8,607,050 t (2000) and 9,112,435 t (2001), respectively (Figure 2). During 1999–2001, average percentages of shellfish, algae, fish, shrimp + crab, and others were 81.01, 11.33, 4.09, 3.24 and 0.33% total production, respectively. Shellfish were the biggest contributor to total production, followed by algae, fish, shrimp and crab. Among cultivated shellfishes, abalone, scallop and mussel farming are an important part of mariculture. Production of mollusks is increasing, due to rising market demand and the fact that wild animal populations are declining.

According to data from SOA (2002) and the China statistical yearbook of aquatic production 1999, Fisheries Bureau, Ministry of Agriculture, the total area used for mariculture rose on average by 10% per year from 277,000 to 715,000 ha between 1985 and 1995. By 1998, the production area had increased to 1,004,407 ha. The total mariculture area was 1,094,000 ha in 1999, 1,244,000 ha in 2000 and 1,286,000 ha in 2001. The area of shallow seas, bays and intertidal mud flats under culture increased from 87,000, 155,000 and 345,000 ha in 1993 to 289,000, 245,000 and 752,000 ha in 2001, respectively. During this period, the areas were used mainly for shellfish, shrimp, crab and finfish production. Mariculture activities have been expanded in all coastal provinces, especially in Shandong and Liaoning in the north, and Fujian and Guangdong in south.

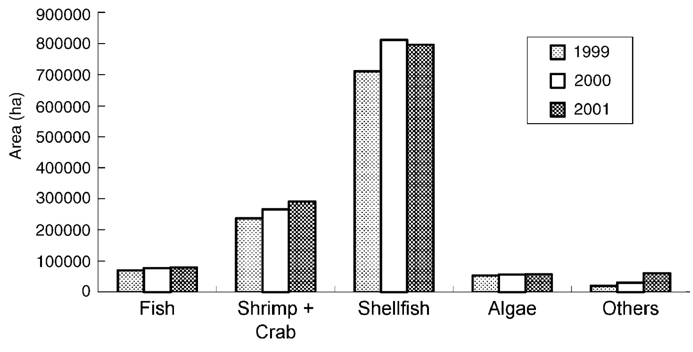

Figure 3. Mariculture area in Chinese coastal waters during 1999–2001. Data sourced from SOA (2002).

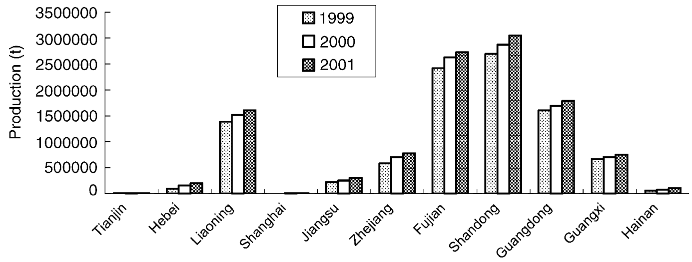

Figure 4. Mariculture production of Chinese coastal regions during 1999–2001. Data sourced from SOA (2002).

Between 1999 and 2001, the area of shellfish production reached 711,000 ha in 1999, 812,000 ha in 2000 and 797,000 ha in 2001 and ranked number one in all mariculture production (Figure 3). Average percentages of shellfish, shrimp + crab, fish, algae and others in total mariculture area was 64.03, 21.97, 6.27, 4.64 and 3.09%, respectively during the 3 years.

The mariculture production of Chinese coastal regions increased during 1999–2001 (Figure 4). For example, the production of Shandong province reached 2,697,852 t in 1999, 2,872,290 t in 2000 and 3,050,657 t in 2001. The highest ranked provinces, Shandong, Fujian, Guandong and Liaoning, produced on average 2,873,600, 2,590,702, 1,696,250 and 1,507,207 t during these 3 years, respectively. Percentages of production in Shandong, Fujian, Guangdong and Liaoning were 27.22, 24.54, 16.07 and 14.28% total mariculture production, respectively. The production of Shandong and Fujian were the biggest contributors to Chinese mariculture. They accounted for over 50% of the total production.

Impacts of mariculture

Accelerated development of mariculture in the past few decades has created negative environmental impacts, such as extensive conversion of mangrove stands to ponds, changes in hydrologic regimes in enclosed waters due to the proliferation of aquaculture structures and the discharge of high levels of organic matter into coastal waters. Also, the increasing discharge of domestic, agriculture and industrial wastes into coastal waters has resulted in a deterioration of coastal water quality and affected aquaculture production and profitability. Furthermore, the increased frequency of red tides in the region poses serious threats to Chinese mariculture industry (Qian et al., 2001).

The environmental effects of mariculture depend on species, culture method, stocking density, feed type, hydrography of the site and husbandry practices (Wu, 1995). In areas where unsustainable practices have been followed, high oxygen deficits and microbial loading have resulted in high mariculture losses. The impact on coastal aquaculture of such water quality deterioration, together with other contaminants, will have a significant bearing on the expansion of mariculture. For example, the increasing frequency of red tides, which devastated shrimp farms in the north Chinese coastal waters, poses a serious threat to future development (Wu et al., 1994; Liu and Liu, 2001).

Economically important animal culture

Marine animal culture can supply live seafood to consumer markets and increase farmers' income, so the animal culture industry developed rapidly in China. Fish, shrimp, oyster, scallop and abalone are the main cultivation animal species, and their large-scale culture has raised important concerns.

Marine fish are commonly cultured and fed with small fish unsuitable for human food. In many marine fish culture zones, high organic and nutrient loadings are mainly generated from uneaten feed, and fish excretions. Uneaten mariculture feed is one of the most important controllable sources contributing to organic and nutrient loadings in coastal areas. Uneaten feed and excretion loadings are much higher in cage culture systems where small fish are used as feed (Hansen et al., 1990; Wu, 1995).

Fish feed introduces large amounts of organic and inorganic nutrients into the fish farm and adjacent bay. Low quality fishes and small-size by-catch fishes from other fisheries are among the feeds commonly used in China. High protein (nitrogen) content is one characteristic of by-catch fishes. Dead by-catch fishes that are used as feed are generally small fishes of 10–15 cm in body length, and are purchased from small markets near the mariculture zones. These fishes are then minced into 2–3 cm pieces in length. In general, fish farmer feed 2–3 times each day and 2–3 kg fish are fed in fish cages (3 × 3 m) each day. Qian et al. (2001) found that minced fish had higher immediate pollution levels than whole fishes and mollusks. In general, 85% of phosphorus, 80–88% of carbon and 52–95% of nitrogen input into a marine fish culture system as feed may be lost into the environment through uneaten feed, fish excretion, and respiration. Despite the high pollution loadings, 23% of C, 21% of N and 53% of P of feed input into the culture system accumulate in the bottom sediments. The major impact is on the sea bottom, where high sediment oxygen demand, anoxic sediments, production of toxic gases and a decrease in benthic diversity have been observed (Wu, 1995).

In a monoculture fish farm, the profile of nutrient flow is complex and governed by the metabolism and interactions between various organisms such as fish, phytoplankton and bacteria. Major sources of nutrients are fish excretion and fish feed. In addition, some bacteria degrade the organic detritus in fish farms and release dissolved inorganic nutrients to the water. On the other hand, direct uptake of nutrients is achieved through the activities of nearby algae and bacteria. Ammonia and urea excreted by fish can be readily taken up by phytoplankton or macrophytes, and may stimulate their growth. Lam (1990) indicated that higher nutrient concentrations result in an increase in phytoplankton growth in marine fish culture zones. Eutrophication or algal blooms often occur in such nutrient-enriched environments. Furthermore, high bacterial content in aquaculture waters may significantly deteriorate water quality by lowering the DO and pH (Qian et al., 2001). Decrease of dissolved oxygen may extend to up 1 km away from the fish farm where trash fish are used and culture conditions are poor (Wu et al., 1994; Liu and Liu, 2001).

Shellfish cultivation is one of the most important forms of mariculture in China. It is largely extensive, requiring no artificial food input, since the animals obtain all their nutrition from phytoplankton, microphytobenthos and different types of organic detritus. Nevertheless, the rapid growth of the industry has inevitably raised questions of carrying capacity and sustainability. Sun et al. (1998) reported that intensive raft culture (scallop and kelp) reduced sea water flow speed by 50%, and water exchange rate deceased 1.7% in comparison with 10 years ago (the beginning period of mariculture in 1982). Cultivation of scallop, oyster and other shellfish has developed so fast in many Chinese coastal waters in recent years that all culture grounds are occupied with exceptionally dense animal populations. Large-scale shellfish can increase dissolved inorganic nutrient concentrations by increasing remineralisation of particulate organic material. This nutrification can result in various negative local environmental effects such as eutrophication, oxygen depletion, biodiversity modifications and pollution of the surrounding waters (Fang et al., 2001; Troell et al., 2003).

In general, animal cultivation resulted in several environmental problems in Chinese coastal waters:

(1) Most mariculture zones are located in relatively sheltered shallow sea areas. Densely cages with fish and overcrowded rafts with shellfish are fixed in a special area with slack water movement and little flushing, thus limiting the dispersive capacity for pollutants, further exacerbating the local water pollution problems.
(2) In most fish culture zones, there are solid constructions on the rafts which house watchmen spend day and night there. In some zones, the watchman population can exceed 100; they live in the zones and form a village on the sea (eg. Shenao fish village on the sea, in Nanao of Guangdong Province). Human wastes constitute an additional pollutant loading and a source for floating refuse in these areas.
(3) The accumulation of waste feeds and fish faeces in the sediment give rise to anoxic conditions resulting in an anoxic layer of sediment and bottom waters depleted in oxygen. Under anoxic conditions, ammonia, hydrogen sulphide and methane are released from the sediment, posing a threat to fish, shellfish, as well as other marine organisms. Upwelling of oxygen-depleted bottom water can kill cultivated animals.

Table 2. Main environmental problems in typical mariculture areas in China

Site	Main cultivated species	Main problems	Resources
Sungo Bay (Shandong)	*Chlamys farreri*	Low growth rate, high mortality rate carrying capacity and self-purification decrease.	Fang et al. (2001) Sun et al. (1998)
Xiamen Sea Area (Fujian)	*Lateolabrax japonicus* *Saccostrea cucullata*	High density of Enterobacter	Ke et al. (2002)
Zhelin Bay (Guangdong)	*Sparus macrocepalus* *Pagrosomus major* *Plectorhynchus cinctus* *Mugil cephalus*	Low DO, High COD, High concentrations of PO_4-P and NO_2-N High concentrations of sulfide and PO_4-P in sediments	Gan et al. (2000)

(4) Animal cultivation produces nutrients such as nitrogen and phosphorus. Any substantial increase in the concentration of dissolved nutrients can lead to an increase in phytoplankton growth. Enhanced phytoplankton growth could be a threat to cultivated animals if the algal bloom consists of toxic species. Algal blooms and decomposition can also deplete oxygen in the water, causing animals dead (Nishimura, 1982; Lam, 1990; Qian et al., 2001).

Some environmental problems in typical mariculture zones in China are listed in Table 2.

Seaweed cultivation

While all cultivated seaweeds play a role in cleaning their surrounding environment by removing nutrients in seawater, *Laminaria*, *Undaria*, *Porphyra* and *Gracilaria* have been the most important species traditionally cultivated along the Chinese coast (Tseng and Fei, 1987; Tseng, 2001; Yang and Fei, 2003). During the 1950s–1970s, the main mariculture organism was seaweed, such as *Laminaria* and *Porphyra*. Now the tend is for farms to be engaged in raising fish, shrimp, crab and shellfish. These systems provide good jobs with better economic dividends to China. However, the ecological role of cultivation of seaweed and economically valuable animals is quite different. Cultivated seaweeds have very high rates of productivity and grow well in water bodies with higher nitrogen and other nutrients. Seaweeds are able to absorb large quantities of nitrogen, phosphorus and carbon dioxide, produce large quantities of oxygen, and, consequently, reduce eutrophication. For example, the large-scale cultivation of *L. japonica* has reduced the negative effect of scallop cultivation in north China (Fei et al., 1999). Another interesting example is Xiangshan Bay, in Zhejiang Province. It was a fertile bay because of high density *Laminaria* in the 1970s, but the bay became seriously polluted with numerous incidents of red tide after farmers switched to high density in fish cages and overcrowded shellfish rafts. In 2001, mariculture production of fish, shellfish + shrimp + crab, and seaweeds reached 9109, 49,092 and 2330 t, respectively in the bay. The percentage of seaweeds was only 3.9% total production (Zhang et al., 2003).

The productivity of cultivated seaweed is usually much higher than that of seaweed in its natural habits. Cultivated seaweeds are able to accumulate considerable biomass over a period of months or years depending on the cultivation season. Large amounts of C, N and P are accumulated into seaweed tissues at the same time. When seaweeds are harvested, nutrients are removed from the sea area. Methods for treating effluents from eutrophic waters with macroalgae were initiated in the mid-1970s. This approach has recently gained new interest, verifying that wastewater from intensive and semi-intensive mariculture is suitable as a nutrient source for seaweed production, and that integration with seaweeds significantly reduces the loading of dissolved nutrients to the environment (Fei et al., 1999; Troell et al., 1999; Chung et al., 2002).

To exploit nutrients as a resource input, and at the same time reduce the risk for eutrophication of the environment, co-cultivated systems with *Gracilaria chilensis* and fish have been developed in Chile in recent years. The results showed that 1 ha cultivation of *G. chilensis*, close to salmon cages, had the potential to remove at least 5% of dissolved inorganic nitrogen and 27% of dissolved phosphorus released from the fish farm. Economical and environmental advantages could be achieved by integrating the cultivation of seaweed with fish farming in open sea systems. Extrapolating for a whole year, a *Gracilaria* cultivation of 1 ha will produce 258 metric tons wet weight per year, or 34 metric tons dry weight. Harvest of *Gracilaria* would then remove 1020 kg nitrogen per year bound in the algae, correspond to 6.5% of the dissolved inorganic nitrogen effluents from the fish farm, as well as 374 kg of phosphorus per year, representing 27% of dissolved phosphorus effluents. Seaweeds used as biofilters in intensive mariculture systems (Troell et al., 1997, 1999).

Our aquarium experiments (fish and seaweed culture systems) results demonstrated that *G. lemaneaformis* can effectively remove inorganic nutrients from waters. The concentrations of NH_4^+-N decreased 85.53 and 69.45%, and the concentrations of PO_4-P decreased 65.97 and 26.74% in the aquariums after *Gracilaria* was cultivated 23 days and 40 days, respectively. *Gracilaria* is a good biofilter of nutrients (authors, unpublished data).

Sustainable development strategy

In recent years, people have become increasingly aware of the dynamic nature of fishery systems. The systems include not only the fish and their environment, but also people and their associated social and economic institutions and communities. Some reports emphasize the challenges to biological, economic, and social sustainability of fishery systems: complexity, change, variability, and measurement error. These characteristics lead to uncertainties, which in turn create risks – biological risks for aquatic ecosystems, economic risks for industry, and social risks for coastal communities (Campbell, 1994; Caddy, 1999; Peterman et al., 1999; Liu and Liu, 2001).

Mariculture can be a sustainable development, provided pollution loadings generated by fish and other animals are kept well below the carrying capacity of the water body. Effects can be significantly reduced by careful site selection, maintaining long-term health of coastal environment, control of stock species and density, improved feed formulation and integrated culture (with macroalgae, filter-feeders and deposit-feeders) (Wu, 1995; McVey et al, 2002).

Coastal environment management

The coastal environment is an important resource. Pollution created by human activities on land should be fully controlled and, therefore, nutrients from terrestrial origins could be decreased. For near-shore resources, governments and users should incorporate ecosystem considerations, including environmental fluctuations and socioeconomic factors. Coastal communities should use the resources in sustainable ways. High priorities for management of marine resource are rebuilding depleted resources and restoring habitats, with concern for maintaining genetic and ecological diversity (Caddy, 1999). While environmental impact assessment (EIA) tends to become a standard requirement for major developmental projects, the application to mariculture is much less common. Indeed, EIA helps to prevent conflict between coastal users, protects sensitive habitats and is important for sustainable development of the mariculture industry. Since nitrogen and organic wastes are major concerns, the susceptibility of the site to dissolved oxygen changes and nitrogen pollution should be given special attention in any EIA of mariculture zones (Wu, 1995).

Controlling the species and density of commercially cultivated animals

Many studies demonstrated that environmental impacts of mariculture varied considerably among sites and were highly dependent on water circulation, stocking species and density, husbandry practices and feed types (Wu et al., 1994; Fei et al., 1999; McVey et al., 2002). At one site in Hong Kong with good flushing and low stocking density, benthos (even corals) could be found underneath fish cages (Wu, 1995). These results clearly indicate that mariculture can be a sustainable industry provided that stocking species and density do not exceed the carrying capacity of the water.

Remove pollution by integrated culture

Ongoing attempts to optimize traditional integrated aquaculture and adopt eco-friendly practices have also helped to sustain and increase production.

Some cultivated seaweeds have very high productivity and can absorb large quantities of N, P and CO_2, produce large amounts of O_2 and have excellent effect on decreasing eutrophication. *Gracilaria lemaneaformis* and *Porphyra haitanensis* are two good candidates. Their yields are up to 40–80 and 30–60 t/ha, respectively. The first author of this paper investigated that the yield of *G. lemaneaformis* reached 50 t/ha in Nanao Sea area of Guangdong Province in 2002. Fifty tons of seaweed can fix 1250 kg C and 125 kg N. The seaweeds effectively absorbed nutrients in the mariculture areas. In addition, seaweed can be widely used as food, fodder, raw material for chemical products and organic fertilizer. Large-scale seaweed cultivation will benefit both the environment and local economics. It could be a powerful method for removing large amounts of nutrients and for bioremediation in marine animals areas (Fei et al., 1999).

Cultivating seaweeds and animals (such as fish, shellfish) together complement each other ecologically. But at present, in most Chinese aquaculture areas, animal cultivation exceeds and is out of balance with seaweed cultivation and in extreme cases, only fish and shellfish are cultivated. The authors believe that developing as much seaweed cultivation as possible in these areas is the most effective approach and will help form an ecologically balanced culture environment.

Seaweed can take N and P, where as filter-feeders (e.g. bivalves) can remove particulate and phytoplankton from water. Harvesting nutrients generated by marine fish-farming by seaweed and filter-feeders would be an attractive option since this would alleviate nutrient pollution on one hand and increase productivity on the other (Wu, 1995; Yang and Fei, 2003). Culturing shellfish to remove N and plankton production derived from fish-farm pollution appears to be a viable and practical option and should be adapted to open-cage culture systems. However, caution must be exercised to avoid bacterial contamination of shellfish from fish farms (Wu, 1995).

Filter feeders can remove and benefit from nutrients in fish farms in two important ways. First, they consume organic particulates and prevent further release of nutrients from the bacterial degradation of organic matter. Second, they also feed on nearby bacteria and phytoplankton that use inorganic nutrients for their growth. Cultivated filter-feeding bivalves, such as scallops and mussels are, therefore, suggested in the integrated cultural system because they consume organic particulates that originated from the fish feed and they directly lower the extent of organic pollution. Moreover, they remove dissolved inorganic pollutants through consumption of the nearby phytoplankton population and thus they reduce the fouling rates in fish cages and nets (Qian et al., 2001).

Traditional polyculture may include combinations of shellfish, finfish and macroalgae, which are more sustainable than monoculture, due to the reutilization of waste products of one species by another. Sustainable aquaculture development will need to recognize the diversity of aquaculture practices as well as the social, economic and environmental conditions in which they will take place (Chopin and Yarish, 1999; McVey et al., 2002).

Fisheries management strategy

The introduction of management measures to mitigate deteriorating coastal water quality and the adverse environmental impacts of mariculture development has now become urgent in Chinese mariculture zones. Fishery is a land-use activity, just like farming or forestry. Though it seems strange to talk of the production of fish as being a land-use just like the production of sheep or trees, the coastal waters in which fish live are intimately affected by the nature of the adjacent land and everything that happens on that land (Campbell, 1994).

High quality fishery production requires good water environments, however, fish-cage farming has been regarded as a source of organic pollution. Therefore, integrated management is necessary. Development of integrated mariculture (e.g. fish + seaweeds) may help the aquaculture industry avoid noncompliance, and gain both direct and indirect benefits from improving water quality and coastal ecosystem health (Troell et al., 2003).

The human component is often the neglected aspect of fisheries management – Fisheries management = Fish + Fishermen. The fish element is relatively easy to handle. Fish are creatures which obey the laws of physics, chemistry and biology and can be reasonably predictable. Fishermen are considerably less predictable and meeting their needs, in terms of the quality of the fish culture operations and the quality of environment in relation to their willingness to pay, is a far less accurate science. No pay infers No fishery.

Quality objectives for the culture ecosystem in relation to eutrophication are to reduce algae growth, increase water clarity, and re-establish the richness in biodiversity. The key to improving and maintaining the long-term health of fish culture zones lies in instituting management for the whole watershed. A control plus management strategy should be implemented in mariculture zones:

(1) Control fish-stocking rate and total of people involved in both fisheries and aquaculture, and restrict the total number of fish cages in all fish culture zones.
(2) Periodic shift of raft (cages) and 1–2 years' fallow (suspending fish-culture activities) to facilitate the recovery of sediment underneath the cages.
(3) Develop submerged cages, which will undertake fish-culture operations in deeper and well-flushed waters. Support and stimulate offshore marine fish-farming.
(4) Consider the dredging of sediments to remove the polluted layer as an alternative method.
(5) Minimize the amount of leftovers by using the appropriate amount feed in the fish culture when feeding practices in fish farms. Encourage the use of pellet foods rather than raw waste fish.
(6) Cultivate seaweed to reduce eutrophication and remediate coastal waters, especially in economical animal culture zones with high stocking rates.
(7) Collect, analyze, and openly communicate data and information. Clearly define the roles, rights, and responsibilities of all fishery participants to align their interests with the overall objectives of sustainability.
(8) A successful management of fisheries depends upon establishing partnerships and fostering interactions between experts in a number of different but related disciplines. Mariculture can be a sustainable development, if the industry is properly managed.

Conclusions

The rapid development and changes in mariculture species have aroused increasing concern about mariculture's impact on the coastal environment. In areas where unsustainable practices have been conducted, high oxygen deficits and microbial loading have resulted in high mariculture losses. Decrease in dissolved oxygen and increases in BOD and nutrients (P, organic and inorganic N and total C) are generally found in the water column around fish farms. The impact on coastal aquaculture of such water quality deterioration, together with other contaminants, will have a significant bearing on the expansion of mariculture. For example, the increasing frequency of red tides, which devastated shrimp farms in the north Chinese coastal waters, poses a serious threat to sustainable development of mariculture.

Fishery is a ecosystem use, just like farming or forestry. Mariculture can be a sustainable development, provided pollution loadings generated by fish and other animals are kept well below the carrying capacity of the water body. Effects can be significantly reduced by careful site selection, maintaining long-term health of coastal environment, control of stock species and density, improved feed formulation and integrated culture. In present situation, it is imperative that the density of fish-stocking and other economical animals such as oyster and scallop is controlled, in addition to restricting the total number of net-cages in the mariculture zones in China. The authors suggest periodic moving of rafts (cages) and development of a fallow system in which fish culture will suspend for 1–2 years in an area to facilitate the recovery of the polluted sediment. Moving fish culture offshore into deeper waters is also suggested. The authors also believe that large-scale seaweed cultivation will reduce the eutrophication in mariculture zones in China.

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