Aquaculture site selection and carrying capacity management in the People's Republic of China

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Abstract

Fisheries have provided about 1/3 of animal protein to 1.3 billion Chinese people, and made significant contribution to improving Chinese living standard and food security. As the largest aquatic food producer in the world, the People's Republic of China has exploited most of its waterbodies and land that suitable for aquaculture. This paper has reviewed the aquaculture site selection and carrying capacity management status in the People's Republic of China. Factors relevant to aquaculture site selection in the People's Republic of China include functional zoning scheme of local land and water areas, water and other environmental quality requirements, influence to local environment and the influence to community welfare. Local issues like such as carrying capacity farming, environmental pressure and deterioration caused by industrialization, rapid expansion of inland freshwater shrimp farming and predicament in the aquaculture related law enforcement are identified as major problems related to the sustainable development of aquaculture. The status of virtual tools (e.g. databases, models) usage and factors related to EAA in the People's Republic of China are also analysed. The continuous increasing of fed animals' portion in the aquaculture structure indicates it is weakening in net food production and increasing environmental pressures in the People's Republic of China's aquaculture industry. Problems in water area zoning scheme enforcement, lack of effective monitoring and legislation on aquaculture effluent discharge are the current bottlenecks limiting reasonable aquaculture site selection and carrying capacity management in the People's Republic of China, and some relevant recommendations have been provided.

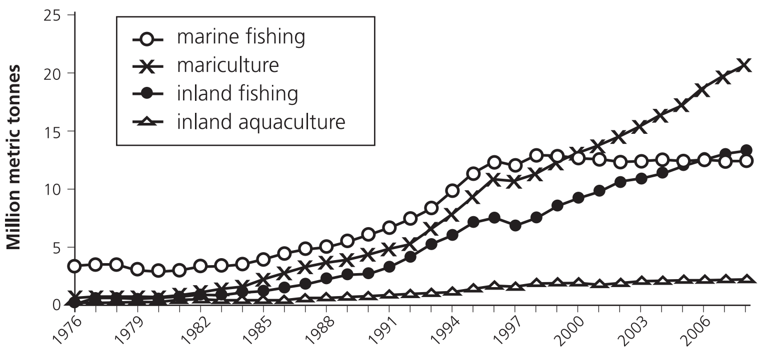
Introduction

The People's Republic of China has the largest aquaculture sector in the world in terms of both the volume of aquatic animals produced and the number of species cultivated. In 2006, the People's Republic of China contributed 67 percent of the world's supply of cultured aquatic animals and 72 percent of its supply of aquatic plants (FAO, 2009).

Status and trends of aquaculture in the People's Republic of China

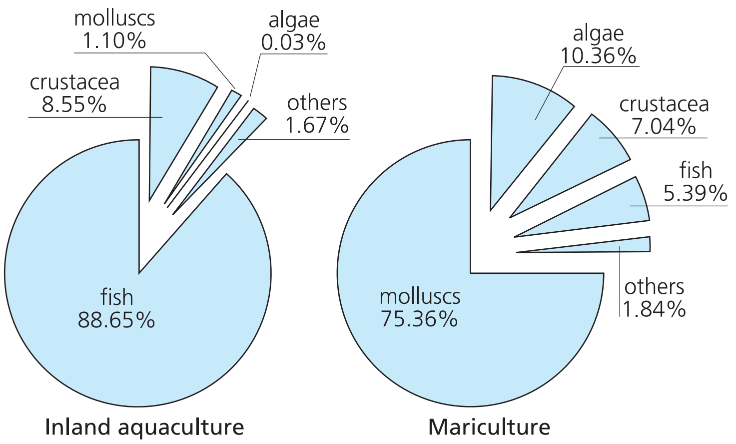
Since 1982 aquaculture in mainland of the People's Republic of China has been developing rapidly, the production of aquaculture has overrun the production of capture, and the production of mariculture has overrun marine fishing (Figure 1). Due to over fishing in inland and coastal waters, fisheries increment in the People's Republic of China (PRC) will mainly come from aquaculture in the near future.

FIGURE 1
Fisheries Production in China (mainland, tonnes)



Source: Fisheries Bureau, Ministry of Agriculture, PRC (2009).

FIGURE 2
Aquaculture production and composition of China in 2008



Source: Fisheries Bureau, Ministry of Agriculture, PRC (2009).

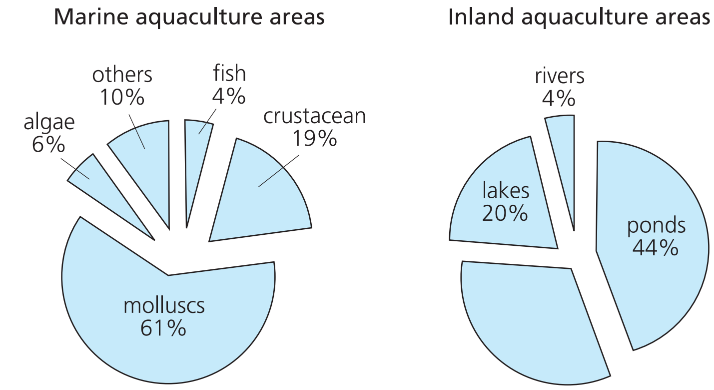
In 2008 the aquaculture production of the People's Republic of China was 34.1 MMT, in which inland aquaculture took 61 percent (Fisheries Bureau, Ministry of Agriculture, PRC, 2009). It can be seen (Figure 2) that molluscs (75.2 percent) are the main component of mariculture production and fishes (88.6 percent) are the main component of inland aquaculture production. The People's Republic of China produces 77 percent of all carps (cyprinids) and 82 percent of the global supply of oysters (ostreids) (FAO, 2009). In general, aquaculture in the People's Republic of China is a high ecological efficiency industry because of the high production of low trophic level carps (freshwaters) and molluscs (marine). Fisheries have provided about 1/3 of animal protein to 1.3 billion Chinese people, and made significant contribution to improving Chinese living standard and food security (Dong, 2009).

Factors relevant to site selection for aquaculture in the People's Republic of China

The People's Republic of China has a long history of aquaculture, particularly for inland freshwater aquaculture, which began 3000 years ago. In the People's Republic of China, the most important inland aquaculture sites are ponds, reservoirs and lakes, respectively contributed 70.4 percent, 11.6 percent and 7 percent to the total inland aquaculture output. Mariculture takes place in three forms: in the sea, on mud flats and land based (ponds), contributing respectively 50.3 percent, 38.5 percent and 11.2 percent to its total marine output in 2008 (Fisheries Bureau, Ministry of Agriculture, PRC, 2009). The area distribution of mariculture and inland culture (mainly fish) is shown in Figure 3, which indicates that shellfish culture covers the biggest area in the sea, and ponds are the most important fish farming measure in freshwater culture.

There is not a special law or legislation on aquaculture site selection in the People's Republic of China, but relevant provisions exist in many comprehensive laws and regulations dealing with fisheries and aquatic environments, including Fisheries Law of PRC (1986, 2000, 2004), Regulator Law for Sea Area Usage (2001), and over 25 legislative instruments (Zhijie, 1989; Cao and Wong, 2007) addressing issues such as regulations on Water Quality Standard for Fisheries (GB11607–1989), Sea Water Quality Standard (GB3097–1997), Environmental Requirements for Origin of Non-environmental Pollution Aquatic Products (GB/T 18407.4–2001), Water Drainage Standard for Mariculture (2007), Requirement for Water Discharge from Freshwater Aquaculture Pond (2007), Marine Protected Areas (1994, 1995, 1997), Environmental Impact Assessment (2002) (Lindhjem *et al.*, 2007), and the implementation of the UNCLOS Convention in 1998 (Keyuan, 2001). In general, there are four main factors affecting aquaculture site selection in the People's Republic of China:

FIGURE 3
Area distribution of mariculture and inland aquaculture of China in 2008



Source: Fisheries Bureau, Ministry of Agriculture, PRC (2009).

Functional zoning scheme of local land and water areas

All the land and water areas in the People's Republic of China are state owned, so the use of land and water area (e.g. aquaculture) must fit the local functional zoning scheme. For example, Functional Zoning Scheme of the Coastal Areas of Guangdong Province was issued in 1999 (People's Government of Guangdong Province, 1999), which specified the coastal area into different function zones, functions for the zones included: natural resources protection, industry, harbor, aquaculture, sewage draining, etc. In 2004, Aquaculture Planning for Inland Water Area and Coastal Zone of Guangdong was approved by the provincial government, which setup the guideline for the aquaculture development and management of local authorities. In order to fulfill such regulations, the aquaculture farm license provision came into force since 2002; license became the precondition for any new farm development since then, and old farms were also requested to post-register the license in a given period.

Water and other environmental quality requirements

Water quality and other environmental factors requirements are also established in those aquaculture related laws and regulations of the People's Republic of China. For example, the Water Quality Standard for Fisheries (GB11607–1989) specified the water quality requirement for aquatic animals and plants growth and reproduction. Along with increasing international communication on food quality safety and legal system development since 1990s, regulations such as Sea Water Quality Standard (GB3097–1997), Environmental Requirements for Origin of Non-environmental Pollution Aquatic Products (GB/T 18407.4–2001), Water Quality Standard for Mariculture (NY 5052–2001), Water Quality Standard for Freshwater Aquaculture (NY 5051–2001) etc. have formulated more detailed environmental requirements for new and existing aquaculture farms, and they co-act with the farm license system.

Influence on local environment

The People's Republic of China enforced Environmental Protection Law in 1989, Marine Environmental Protection Law in 2000; more and more standards addressing the environmental influence of aquaculture farms such as Water Drainage Standard for Mariculture (SC/T 9103–2007) and Requirement for Water Discharge from Freshwater Aquaculture Pond (SC/T 9101–2007) came into force in recent years. These are the legal restriction on the aquaculture farm construction, running and discharge, which inevitably relate to site selection.

Traditional fish farms in the People's Republic of China are mostly typical polyculture including integrated multi-trophic aquaculture (e.g. inland polyculture of carps; marine shellfish-macroalgae polyculture, etc) or combined with other agricultural sectors such as rice and mulberry fields, the negative environmental cases are seldomly reported. However, the development of intensive farming (e.g. intensive shrimp farming, fish cage farming etc.) since recent years has brought prominent threats to the environment, e.g. fish cage farming in reservoirs and lakes (Ning and Gu, 2004; Ning *et al.*, 2006; Sun *et al.*, 2005) and coastal areas (Wang, Wei and Wen, 2006; Gan *et al.*, 2006; Ge, 2009).

Influence on community welfare

Aquaculture is not only important in ensuring the People's Republic of China's food security in the nation wide, but also important to the community livelihood and welfare locally. There are presently 5.04 million farmers working on this industry (inland and marine). Economic benefit and risk are the predominant factors affecting the decision of new farm construction (including site selection) or shutting down the old farms for the stakeholders.

Continuing industrial development in the People's Republic of China in the recent decades and rural population migration to the coast has led to dramatic increases in nitrogen and phosphorus loading resulting in degradation of coastal water quality and proliferation of HABs (Guo *et al.*, 1998; Hao, Huo and Yu, 2000; Shen, 2001), which has brought serious challenge to the profitability of local aquaculture. For example, the rapid industrialization in the west coast of Shenzhen swept away all the aquaculture farms in late 1990s which had been the main economic source of local people 30 years ago, and the famous Shenzhen Shajing Oyster is left only in the memory of old local people (http://gzdaily.dayoo.com/gb/content/2001-03/06/content_80465.htm). On the other hand, Shenzhen is now the special economic zone of the People's Republic of China, a modern industrial metropolis.

Identifying issues locally specific to species, cultures, and geographies

Farming in excess of the carrying capacity

Although the People's Republic of China has the largest aquaculture industry in the world, there are very few large-scale aquaculture corporations domestically; most of the production comes from millions of small-scale farms owned by individual farmers, which brings the difficulty in coordinating farm scales and distribution for the local fisheries administrative authorities. Rapid growth of aquaculture production in the People's Republic of China prompted by technical progress (e.g. commercial feeds, aerator using, etc.) since the late 1990s has dramatically improved the living standards of part of aquaculture farmers, which has also caused the immoderate expansion of farming scale (Dong, Pan and Li, 1998), over carrying capacity farming has become a common failing in many coastal and inland systems. For example, Sandu Bay (26°35'11"N, 119°47'05"E) is a small semi-enclosed bay (263 km^2) in Fujian Province, which was the original natural distribution area of yellow croaker (*Pseudosciaena crocea*); yellow croaker cage farming started in some coastal regions Sandu Bay in 1995, in which Qingshan region was the main cage farming area, and the bay was soon overloaded (Figure 4a,b,c,d). There were about 1000 fish cages in Qingshan in 1996, but the cage number in this region soared to 50 000 in 2005, and at the same time the total cage number in Sandu Bay turned to 260 000. However, the mass expansion of farming scale has not brought mass benefit, but frequent outbreaks of anoxia, HAB, epidemic fish diseases and mass mortality since then (Fang, 2008; Zhang, 2008). Similar problems also happened to other economic species, such as pearl oyster farming in the Guangdong and Guangxi coast of Beibu Gulf (Fu *et al.*, 2009).

FIGURE 4a
Fish cage farming locations in Sandu Bay

Source: Zhang (2008).

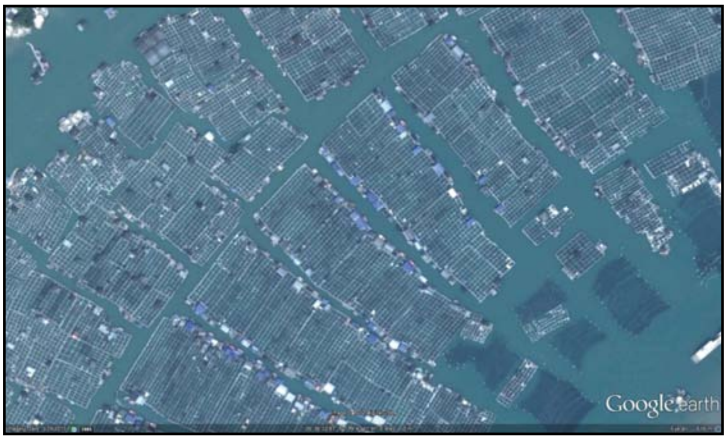
FIGURE 4b
Satellite image of fish cages in Qingshan Region, Sandu Bay

Source: Image © 2012 Digital Globe.

Environmental pressure and deterioration caused by industrialization

The strong development of the Chinese economy, centred mainly on manufacturing, together with the influx of rural populations to urban areas, many of which are located in the coastal zone or near major rivers, have resulted in a substantial increase in nutrient loads, leading to great environmental pressure and deterioration, such as pollution, frequent occurrence of HAB and fish kills etc. (Guo *et al.*, 1998; Hao, Huo and Yu, 2000; Shen, 2001; Xiao *et al.*, 2007). The environmental conditions in many areas are no longer suitable for aquaculture, e.g. the coastal areas of Yangtze River Estuarine and Hangzhou Bay. Both these areas were traditionally important aquaculture bases for Shanghai and nearby cities, but the water environment in the areas were polluted in varying degrees by inorganic nitrogen, organic substances, phosphorus, petroleum and heavy metals, and the contents of all these pollutants had exceeded the standard of fisheries water quality or the first category of seawater quality standard of the People's Republic of China by 2003 (Zang *et al.*, 2003). Red tide and anoxia are the other two typical symptoms in current Yangtze River

FIGURE 4c
Closer satellite image of fish cages in Qingshan Region, Sandu Bay



Source: Image © 2012 Digital Globe.

FIGURE 4d
Fish cages in Qingshan Region, Sandu Bay (2008)

Source: Zhang (2008).

estuarine. There were only 9 red tides occurred in the coast of the People's Republic of China in 1970s, 74 in 1980s, then shifted to 20–30 annually in 1990s, surprisingly the occurrence of red tides in Yangtze River estuarine was 48 in the first six months of 2002, and the affected area was more than 5 000 km^2 (Chen, 2008).

Rapid expansion of inland freshwater shrimp farming

Inland shrimp farming started in the People's Republic of China in the late 1990s, and it was initially developed to reclaim the saline and alkaline wasteland in some coastal and inland areas using local natural low salinity groundwater (Zhu and Dong, 2005). However, the great tolerance to low salinity of the Pacific white shrimp (*Litopenaeus vannamei*) has led to the rapid expansion of shrimp farming to many traditional freshwater agricultural areas since 2001, and it has become an efficient way to increase farming profit (Zhu *et al.*, 2004). In the freshwater area, farmers add salt into the water to keep the salinity at around 3 ppt (He and Wang, 2006). However, in this "freshwater" situation, *L. vannamei* survives better and grows faster at higher salinity, so more and more salt is added by the farmers. By the end of 2008, freshwater shrimp (*L. vannamei*) farming was present in 26 Chinese provinces, and the inland shrimp production in the People's Republic of China was 542 000 tonnes in 2008, while the *L. vannamei* mariculture production was only 520 000 tonnes (Fisheries Bureau, Ministry of Agriculture, PRC, 2009).

Adding large amount of salts into freshwater area could bring disastrous ecological consequences such as land and water salinization, which could even threaten the food security (Zhu and Dong, 2005; Liu and Wan, 2007), similar problems happened in the Kingdom of Thailand in the 1990s (Braaten and Flaherty, 2001), but the potential risk of such activity seems not been realized by relevant agricultural authorities; on the contrary, rice field *L. vannamei* culture is being encouraged by many local fishery agencies around the People's Republic of China (Wang, 2005; Yang, 2009; Zhang, 2009).

Predicament in the aquaculture related law enforcement

Most of the aquaculture farms in the People's Republic of China are located in the rural and suburban area, where local economic condition is not as good as in the cities, and economic development is likely the primary goal of most of the local governments. Aquaculture as an important economic activity is always favoured by the government, so sometimes the unlawful act such as over carrying capacity farming and waste water discharge without treatment are not strictly stopped (Liu *et al.*, 2008). Problems also exist in the legal system itself. For example, the present aquaculture related laws and regulations (e.g. Fisheries Law of PRC) are mostly guidelines and framework for management, which lack practical punitive measures (Liu *et al.*, 2008). Up to now, the pre-construction environmental influence assessment is lacking for new farms (Luo, Zhu and Bao, 2009), and aquaculture effluent fee is still not legally adopted in the People's Republic of China (Dong, 2009).

Use of models and Decision Support tools

Scientific databases such as the People's Republic of China Marine Science Database and South China Sea Marine Science Database have been developed by the institutions of the Chinese Academy of Science (CAS) and available for scientific research and decision-making since 2005 (Huang and Li, 2006).

Modern virtual technologies such as remote sensing and modelling for aquaculture management and ICZM were introduced to the People's Republic of China during the late 1990s through a series of collaborative projects with Europe and North America. Knowledge transfer through these international programs led to the application of some of the Decision-Making tools such as the MOM model for Sanggou Bay (Zhang *et al.*, 2009), the EcoWin2000 and FARM models in Sanggou Bay and Huangdun Bay (Ferreira *et al.*, 2008a), and the POND model for shrimp farms in Zhejiang and Guangdong provinces (Zhu, 2009). However, most of the virtual technology applications for aquaculture management in the People's Republic of China are still limited to the RTD level and few have been used in actual management practice. Nevertheless, the SPEAR project succeeded in actively involving stakeholders from farming cooperatives and local administrators in the iterative process of scenario definition, model application, and review and interpretation of outcomes, using a Driver-Pressure-State-Impact-Response (DPSIR) framework. Currently, a few influential stakeholders such as large aquaculture companies (e.g. Zhangzi Dao Co. Ltd) and high-tech aquaculture feed companies (e.g. Haid Co. Ltd) have begun to apply GIS, remote sensing, and modelling tools either solely or in collaboration with academic institutions (Zhang, Fang and Wang, 2008).

Main gaps and improvement needs according to the EAA

Integrated multi-trophic aquaculture (IMTA) firstly occurred in the People's Republic of China 1000 years ago. In "Jiatai Notes" (1201–1204) it was recorded that "In early spring fingerlings were bought and stocked into ponds, and the quantity often could be tens of thousands, most of them were bighead carp, silver carp, common carp, grass carp and black carp". In "Complete Book on Agriculture" written by Guangqi Xu (1639) it was recorded that "the optimized ratio for stocking silver carp and grass carp was 600: 200, and only the grass carp was fed with grass". The classic polyculture model is still widely being applied in the freshwater ponds all over the People's Republic of China. In mariculture, the bivalve – macroalgae – fish cage combination is also widely used, e.g. Pacific oyster, bay scallop – kelp – puffer fish cage combination culture in Sanggou Bay of Shandong, Chinese oyster – porphyra – yellow croaker fish cage combination culture in Xiangshan Gang of Zhejiang, and Pacific oyster – gracilaria – grouper fish cage combination in Zhelin Bay of Guangdong. Large-scale of macroalga or seaweeds aquaculture is also been used as a bioremediation measure for the degenerated coastal environment (Zhou *et al.*, 2006).

Because of heavy population pressure, the People's Republic of China has exploited most of the waterbodies and land that suitable for aquaculture, just as has happened to farmland for other agricultural sectors since 1980s. As such, recent research and management measures on EAA in the People's Republic of China are mostly focused on the environmental influence assessment and carrying capacity estimate (Miao and Jiang, 2007; Zhang *et al.*, 2007; Jia and Song, 2010) to the aquaculture sites that presently exist, which may be used to adjust the farming scale, reform the overall system scheming, or shut down the unqualified farm (Luo, Zhu and Bao, 2009).

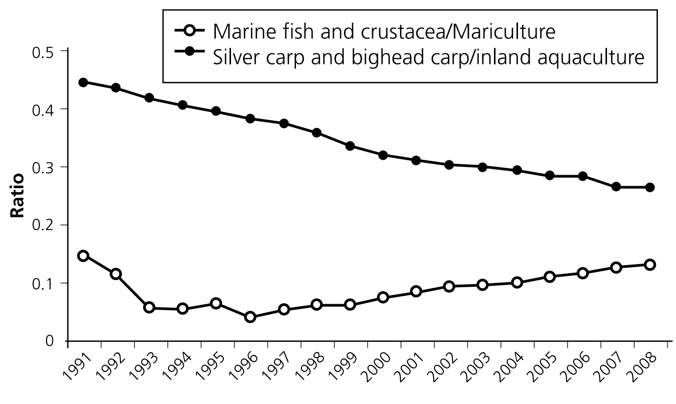
Aquaculture carrying capacity research started with the fish cage culture problems in reservoirs in the People's Republic of China in the 1980s (Li *et al.*, 1989; 1994; Xiong *et al.*, 1993). Carrying capacity research for marine systems started in early 1990s in Sanggou Bay (Fang *et al.*, 1996a, b), followed with a series of international cooperative projects on this topic, e.g. the EU project 'Carrying capacity and impact of aquaculture on the environment in Chinese bays' (1998–2001) and 'Sustainable options for people, catchment and aquatic resources – SPEAR' (2004–2007), and a lot more national projects (Lu *et al.*, 2000, 2001, 2004, 2005, 2006; Zhang, 2008) which together have greatly improved the public perspective on aquaculture sustainability and EAA.

Rapid change of aquaculture structure in the People's Republic of China

Data from the People's Republic of China Fisheries Yearbook (Fisheries Bureau, Ministry of Agriculture, PRC, 1992–2009) indicates that with intensification of farming systems and increment of species farmed in the People's Republic of China the ratio of low trophic level species production is decreasing rapidly (Figure 5). From 1999 to 2008 both productions of mariculture and inland aquaculture were increasing, meanwhile, the production ratio of marine fed fish and crustacean/mariculture increased from 6.2 percent to 12.6 percent and the production ratio of filter-feeder silver carp and bighead carp/inland aquaculture decreased from 35.6 percent to 26.4 percent.

Mariculture production in the People's Republic of China in 2008 was 13.4 MMT, of which fed species took 12.6 percent, in inland aquaculture the production of fed aquatic animals has probably reached 59 percent due to widely feeding of grass carp and tilapia in pond culture. Aquaculture as a whole in the People's Republic of China about 41 percent of aquaculture production came from fed aquatic animals in 2008. Fishmeal consumption in this industry is increasing rapidly. Such development trend indicates the weakening in net food production and increasing environmental pressures in the People's Republic of China's aquaculture industry, just as elsewhere in the world (Naylor and Burke, 2005; Dong, 2009).

FIGURE 5
The changes of the production ratio of marine fed fish and crustacean/mariculture and the production ratio of silver carp and bighead carp/inland aquaculture.



Source: Compiled from Chinese Fisheries Yearbooks, 1992 to 2009.

Identifying current and future issues and bottlenecks

Problems in water area zoning scheme and its enforcement

In May 2002, the Ministry of Agriculture of PRC published the "Trial program for water area and mud flat license system", "Specification for aquaculture water area zoning scheme" and "Outline for aquaculture water area zoning scheme", but only Guangdong, Shanxi, Fujian and Sichuan provinces had published their provincial aquaculture scheme by the end of 2007, and all of these schemes were composed based on water area zoning functions. The ultimate objective of function oriented water area zoning is to optimize the holistic functioning of the whole water system so as to protect the environment, but the current enforcement of water area zoning scheme is based on administrative regions, which aims to inspire aquaculture industry and maximize the economic benefit. The presence of such contradiction has caused the difference in carrying capacity control, aquatic environment quality and social perception on EAA among places (Luo, Zhu and Bao, 2009), e.g. although the carrying capacity for fish cage farming in Sandu Bay was investigated by the Fisheries Institute of Fujian Province during 2005 – 2007and reported that 40 percent of the cages should be removed, the cage number did not change much in the subsequent years (Zhang, 2008). A systematic reform such as setting up specific and independent water area administrative agencies might be a solution (Liu *et al.*, 2008).

Lack of effective monitoring and legislation on aquaculture effluent discharge and its consequence

At present, the intensification tendency in Chinese aquaculture is progressing rapidly, and the direct economic benefit is the main motivation. Because there is no effective monitoring mechanism on aquaculture effluent discharge and relevant legislation on effluent fee, most of the intensive aquaculture farms or areas are not equipped with effluent treatment facility, some may have such equipment but seldom in use. The lack of effective monitoring and legislation on aquaculture effluent discharge has resulted in the fact that intensive aquafarmers and companies haven't taken any responsibility for the ambient environment pollution caused by the farm effluent, which has caused the intensive farming appear with unreal and abnormal economic benefit (Dong, 2009).

Although some internationally growing intensive farming technique such as salmon cage farming and shrimp farming also have deficiencies, e.g. genetic pollution caused by fish escape, disease transmission, destroy of mangroves etc., and some may have caused serious environmental problems in somewhere (Dong, Pan and Brockmann, 2000), but could be evitable if all the needed measures are complete.

Recommendations

Any industry that aims to economic maximization but ignores environmental consequences will inevitably be unsustainable. The People's Republic of China started pond fish farming 3000 years ago, and has been honoured as the cradle of aquaculture. The ecological farming models such as rice field fish farming (ecological aquaculture), fish pond polyculture (some of them were IMTA) and mulberry fish ponds system (recycle economy) were all historically developed in the People's Republic of China, they should be highly promoted in present the People's Republic of China and improved with modern technology (Ye and Zhou., 2008; Dong, 2009).

Aquaculture carries the responsibility for the food security of the People's Republic of China's 1.6 billion people in the near future, and its development has to obey the rules of market economy. Therefore, the development of this industry cannot do without the guidance and support from the government.

For the sake of structure optimization and sustainability of aquaculture industry in the People's Republic of China, legislation and regulation on aquaculture effluent discharge management should be issued as soon as possible, and the product price must include its environmental cost. Aquaculture effluent treatment and recycle must be encouraged by the government and society.

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