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Historical Evolution of Mariculture in China During Past 40 Years and Its Impacts on Eco-environment

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Abstract: The rapid development of mariculture in China in recent decades has satisfied people's demand of seafood, and has made a great contribution to economic development. However, mariculture has also caused some negative impacts on the eco-environment. By statistically analyzing national data (as well as data for four main provinces) regarding the mariculture area and cultivation species in China since reform and opening up, the historical evolution of mariculture during the past 40 years was analyzed, the driving factors related to policy, market and technology innovation were discussed, and the potential impacts of mariculture on the coastal eco-environment were also illustrated. The statistical results indicated that the maricultural area increased radically during the past 40 years, from 1979 (116.47×10^3 ha) to 2012 (2205.65×10^3 ha), with an increase of nearly 20-fold. Shandong Province represented the fastest-growing region, with an increase of 31-fold. Moreover, the cultivated species had gradually become diversified. Initially, shellfish and algae were major species, and then it developed to various species including fish, and currently shellfish and crustaceans were the major species. The development of mariculture was driven by government policies, market economy and technology innovation. Rapid development of mariculture also caused significantly adverse impacts on the eco-environment of the coastal regions. For example, the sea reclamation for mariculture decreased the area and function of coastal wetlands and the contaminants originating from mariculture destroyed the coastal aquatic environment. Fortunately, the implementation of '13th Five-Year Fisheries Planning' is expected to help both improve the seafood quality and reduce the contamination in coastal aquatic environment. This current study will provide reference for management and structure adjustment of mariculture in the future.

Keywords: mariculture; reclamation; coastal wetlands; aquatic environment pollution

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1 Introduction

China is the world's largest fish products production, demand and output country in the world. During the last century, the demand of both fish and other aquatic products (e.g., shrimp, crab, and shellfish) in China has been continuously increasing, which stimulates the development of the aquaculture industry including both freshwater and seawater aquaculture (referred to as mariculture) (Li et al., 2011). Mariculture has a shorter history as compared to freshwater aquaculture. However, the area of mariculture has gradually increased and

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the culture species tends to be diversified in recent decades, and mariculture has become an important component of the aquaculture industry in China (Fan et al., 2005; Cao et al., 2015). Mariculture has created remarkable economic benefits and relieved the pressure of overfishing in the natural fishery resources. However, mariculture also posed negative impacts on the eco-environment. It was reported that the pollution level of offshore waters in China has been constantly increasing, the water quality has been decreasing, and the area of coastal wetlands has been shrinking during the last decades (Zhu, 1999; Li et al., 2006; Wang et al., 2012; Zuo et al., 2012). According to 'China's Environment Quality Bulletin, 2015' (MEPC, 2016), most of the important coastal wetlands are in sub-health status, approximately 80% of the monitored sea water was eutrophic to different extent, and the nutrient contents in some sea areas are beyond the fourth kind of seawater quality standards. Mariculture is considered to be one of the major reasons (the most important source is the terrestrial input) causing the deteriorated seawater quality and the impaired wetland health, as the nutrients (e.g., nitrogen and phosphorus) originating from the unused fodder and the excreta of aquatic organisms produced during the process of cultivation can cause eutrophication, which is referred to as red tides in the ocean (Chen, 2008). The statistical data from 'China's Environment Quality Bulletin, 2015' (MEPC, 2016) showed that, the nutrient loads severely exceeded the limit in some area among monitored 4.867×10^8 ha. Additionally, fodder sometimes contains heavy metals (Liang et al., 2016), which will be bio-accumulated and potentially cause toxicity once they are released into the seawater (Li, 2004; Lei, 2014).

The investigation of the historical evolution of mariculture and its driving factors as well as its potential impacts on the eco-environment can provide reference for both the management of mariculture and the eco-environment protection of coastal regions. However, there are only a few studies regarding the mariculture in China so far, and the available research findings are relatively scattered. There is still a lack of comprehensive information about the spatial and temporal distribution of the area of mariculture and the culture species, the historical evolution trends, the driving factors and the potential impacts on eco-environment. Therefore, the objectives of this study were to: 1) analyze the evolution process of mariculture (including the area of mariculture and the major culture species both in nationwide range and in some major provinces) in China during the past 40 years since the reform; 2) discuss the driving factors from the view of policy, market and technology innovation; and 3) evaluate the potential impact of mariculture on the eco-environment. The results will provide reference for guiding the future development of mariculture and for protecting the eco-environment in coastal regions in China.

2 Change of Mariculture Area since 1979

The mariculture area in China showed a constantly increasing trend from 116.47×10^3 ha in 1979 to 2205.65×10^3 ha in 2012 with ~20 fold increasing percentage, based upon the statistical data from '*Chinese Fishery Statistical Yearbook, 1979–2012* (MAC, 1980–2013)' (we just analyzed the available data) (Fig. 1). However, the annual growth rate of mariculture area varied largely among different periods (Fig. 2). The average annual growth rate during the past 40 years was about 10%. While, the annual growth rate during 1979–1988 was generally greater than all the other periods, which indicated that mariculture developed very fast during this period. It is noteworthy that the fastest growth of mariculture area occurred in 1983–1984, and a growth rate of about 30% was observed in 1984 as compared to 1983. After 1998, the growth rate of mariculture area showed relatively stable trends.

The mariculture area from the nationwide range showed an overall increase during the past 40 years, but due to the different developable marine resources in different regions and the different influencing factors, the change of mariculture area in different regions might vary from each other. Therefore, in this current study, four provinces, Liaoning, Shangdong, Jiangsu and Guangdong, which have a majority area located in and/or make the largest contribution to the entire area of the four estuarine deltas (the Liaohe River Delta, the Yellow (Huanghe) River Delta, the Yangtze River (Changjiang) Delta, and the Pearl River (Zhujiang) Delta, respectively) were selected and the change of their mariculture area over time was analyzed. The overall development of mariculture in the four provinces showed similar trends, and the mariculture area increased over time in all the four selected provinces (Fig. 3).

From 1979 to the early 1990s, the mariculture area did not show much difference among the four provinces, however, the mariculture in Liaoning and Shandong provinces developed faster than the other two provinces since 1993, and the order of mariculture area in the four provinces since 1993 was as follows: Liaoning > Shandong > Guangdong > Jiangsu.

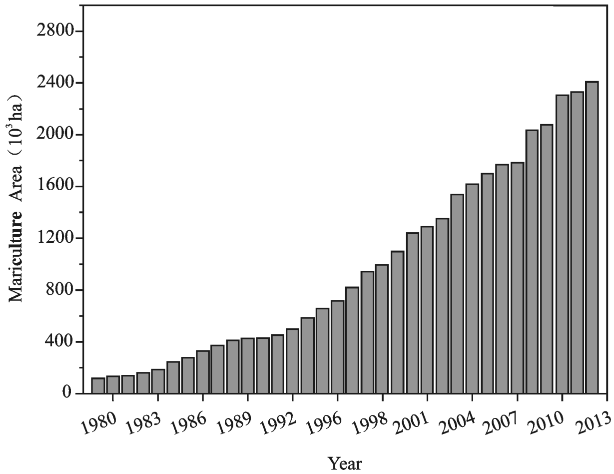

Fig. 1 Mariculture area of China from 1979 to 2012

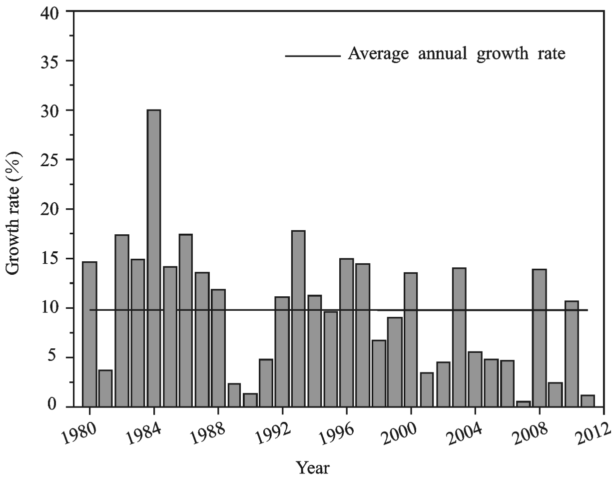

Fig. 2 Annual growth rate of mariculture area in China from 1980 to 2011

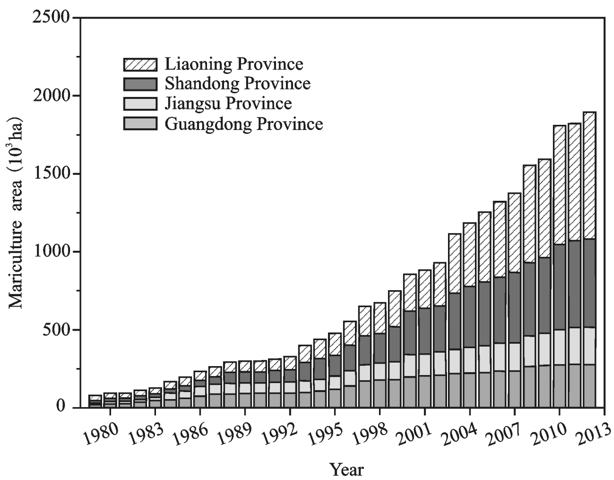

Fig. 3 Mariculture area of different provinces from 1979 to 2012

3 Evolution of Culture Species

With the diversification of people's pursuit of seafood, the implementation of policy, the regulation of the market and the innovation of technology, both the temporal and spatial distribution of the mariculture area varied largely among different culture species. As shown in Fig. 4, in the first a few years after the reform (i.e., year 1978), there were only simple types of culture species like shellfish and algae which basically had the similar cultivation area in nationwide range. The shellfish mainly included scallops and mussels, while algae mainly included seaweed and kelp. The cultivation of fish occurred since the year of 1983, although its cultivation area increased slowly in the following 30 years. Shellfish remained the major culture species and its cultivation area has been increasing during the past 40 years. Additionally, as shown in Fig. 5, more and more species of shellfish have been cultivated, and the species had developed from only scallops and mussels at the beginning to various species including scallops, mussels, abalone, razor clam and clam, etc. Crustaceans which mainly refer to shrimp and crab also developed fast in both cultivation area and species. The cultivation area of algae increased slowly, however, its species (Fig. 5) had developed from only seaweed and kelp at the beginning to various genera and species (e.g., wakame, gracilaria, eucheuma, agar, sargassum, fusiforme, etc).

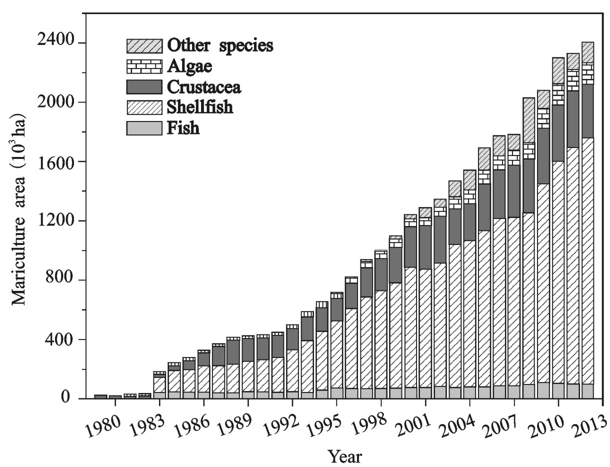

Fig. 4 Culture area of different seafood species in China from 1979 to 2012

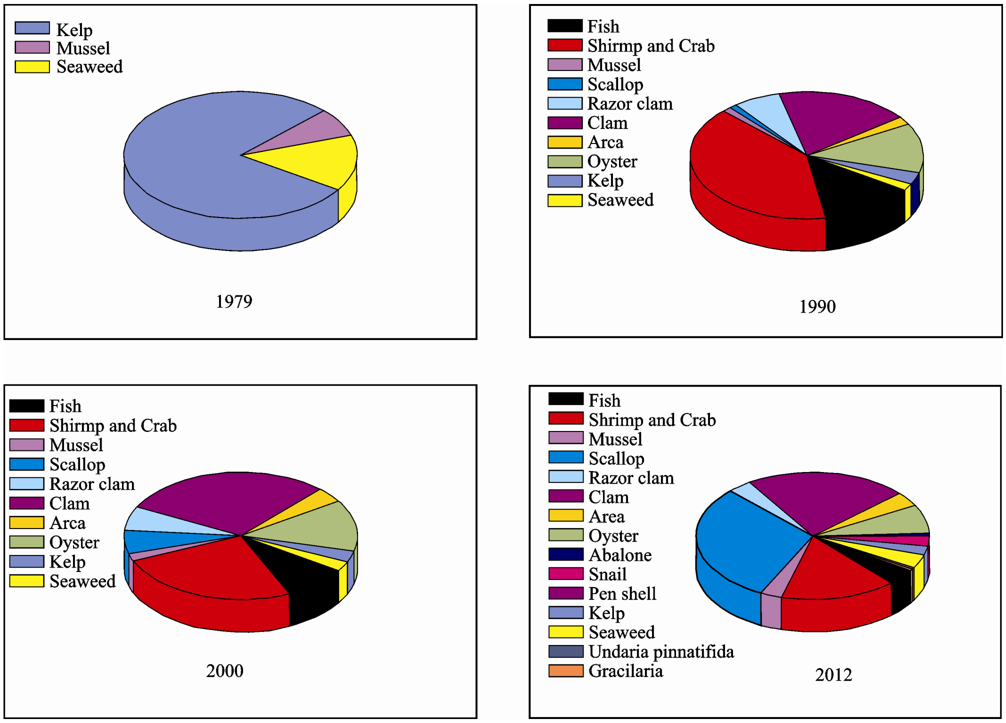

Fig. 5 Mariculture area percentages for various species in China in different periods

The other species which mainly refers to trepang, sea urchin, sea-pearl, jellyfish, etc. are also calculated and presented in Fig. 4. These species did not appear until the year of 1997, and they have gradually taken an important portion of the mariculture.

4 Driving Factors of Mariculture Development

4.1 Role of policy in mariculture development

As a national regulation tool of the marine fishery, the industry policy has regulated and guided the mariculture. The different orientation of industry policies leads to different development characteristics of mariculture in different periods (Zhao, 2013). For example, 'reasonably utilize resources, explore sea fisheries, vigorously develop aquaculture, and focus on improving quality' was put forward in the National Session of Aquaculture held in 1979, which gradually flourished mariculture in the following 10 years (Cheng et al., 2005; Li et al., 2008). However, the growth rate of mariculture area declined in the years between 1989 and 1992, which might result from the increase of the investment in fishery materials and the taxes. So, in the year of 1993, the Ministry of Agriculture of China established a new guideline to keep steady production for the 1990s. This guideline encouraged people to scientifically and reasonably keep exploring new field of production and to steadily expand the cultivation scale of multiple species.

Since the beginning of the 21st century, the local governments and the fishery administrative departments at all levels started to adjust the regional layout that was still based closely around the constructional adjustment of products, and helped to expand further the production space. The adjustment of regional layout gradually started, which was responsible for controlling the growth rate of mariculture area in different regions since the year of 2004.

In 2013, Chinese central government proposed to build the '21st Century Marine Silk Route', which emphasized the sustainable development of the marine economy. Co-operation among countries will be beneficial for pushing the utilization of fishery resources and the development of the fishery industry in most countries along the route, and the pelagic fishery of China will probably develop faster by taking advantage of this opportunity (Chen and Han, 2016), while the increased rate of coastal mariculture area might be controlled accordingly. Under the new situation, the development goal of Chinese mariculture will no longer focus only on increasing yield thereby satisfying the demand. The fishermen are supposed to catch the opportunity and take advantage of the support from the new policy, which will lead to progress in multiple goals. They are encouraged to innovate the fishery technology, to actively develop the predominant species with high quality and high price, and make an effort to construct all-in-one mariculture regions involving advanced cultivation with characteristics of high yield, high quality, and good environment.

4.2 Role of market in mariculture development

Apart from the government guidelines, market is also one of the important factors that impact the development of Chinese mariculture, especially cultivation species. The influence of market demands (both home and abroad) on the cultivation species and yields are different within different development phases. Table 1 showed the exports tendency of mariculture products from 1979 to 1990 (MAC, 1979–2012). In the late 1980s, China adhered to 'go globe' strategy and made efforts to improve the quality of marine products and market supply. Major consumption markets, America, Japan, and Western Europe were in short supply of shrimps and they relied on importing large quantities. Therefore, shrimp farming in China was born at the right moment. In 1979, the total global yield of shrimp products reached 50 000 t, which created an all-time high (MAC, 1979–2012). However, because of the fall of demand for kelp, the supply exceeded the demand, which led to the overstock of large amounts of kelp. Since the 1990s, due to the complete and perfect supporting conditions and facilities in shrimp cultivation, the economic effectiveness was enhanced, and the development of shrimp cultivation had led to a growth of mariculture area of mussels, which were used as a high quality feed for shrimp cultivation (Fig. 5). Consequently, since 1983, especially the years after 1986, the growth rate of the cultivation area of crustaceans (mainly referred to shrimp at that period) had slowed down, while, the cultivation area of mussels grew fast. Although in the latter half of the year 1989, the national economic environment changed and the international market fluctuated for circumstance, the Chinese government actively carried out macro regulation, and maintained the all-round way development of shrimp and mussels cultivation.

Since the start of the 21st century, the marine products market transaction was active and the import and export trading has been increasing rapidly. According to the statistical data from the customs of China, China's total trade of aquatic products in the year 2000 increased by 52.6% as compared to 1999, and the sea products accounted for a large proportion of the aquatic products (Song, 2007). The '21st Century Marine Silk Route' called for the enhancement of international cooperation. For mariculture in China, it is required to carry out the targeted cooperation, and to further enhance the co-operation with countries which already have a basis for co-operation. The key tasks emphasized were to construct the docks, refrigeration storages, and factories for building fishing boats in the coastal areas of countries along the route, and to establish manufacturing bases or sales centers for pushing the exploration of sea fishery resources in China and the development of mariculture under new circumstances (Sun and Zhao, 2011).

Table 1 Change tendency of exports of mariculture products from 1979 to 1990

Year	Total exports of aquaculture products (t)	Exports of mariculture products (t)	Proportion of mariculture in all aquaculture products (%)	Major exports of mariculture species
1979	136430	84915	62.2	Fresh fish and kelp
1980	135540	83434	61.6	Fresh fish and kelp
1981	108933	54523	50.1	Fresh fish and kelp
1982	107324	57541	53.6	Fresh fish and kelp
1983	105350	50163	47.6	Fresh fish, prawn and jellyfish
1984	72315	27173	37.6	Prawn and fresh fish
1985	42032	33546	79.8	Prawn and fresh fish
1986	59045	46995	79.6	Prawn and fresh fish
1987	46181	36428	78.9	Prawn and fresh fish
1988	44845	39952	89.1	Prawn and fresh fish
1989	37602	34642	92.1	Fresh fish, prawn and dried small shrimp
1990	65888	50943	77.3	Fresh fish and prawn

4.3 Role of technology innovation in mariculture development

In addition to the policy and market, technology innovation also stimulated the mariculture development. There are many traditional mariculture industries in China, however, some of their disadvantages appeared during the transformation and promotion processes. For example, marine resources were consumed excessively and the marine environment was polluted with the development of traditional competitive industries. Therefore, technology innovation as one of the major driving factors should be carried out to improve traditional mariculture industries (Yao, 2015).

In the past 40 years, technology innovation which was included in seeding, culture species, culture method and high efficiency feed techniques has contributed much to mariculture development. In the 1980s, the seeding technique of shrimps developed quickly and flourished mariculture (Song et al., 2016). New varieties such as jerk filefish in the 1970s and anchovy in the 1980s effectively expanded the mariculture area, which brought highly efficient techniques methods for different marine regions (Yang, 2006). Culture methods (like culture in industrial farming, in cage and in running water) as high efficient culture techniques, were applied in the 21st century and improved the quality of marine environment (Yang, 2006). In the new period, the development of ecological and healthy mariculture is urgently required, which demands technology innovation to reduce and remove the disadvantages in traditional mariculture industry.

In general, the policy, market and technology innovation as one inseparable system were dominant factors affecting the development of mariculture, especially when a new cultivation species was introduced. During continuous development, the market and technology innovation usually showed more impacts but they required the support of appropriate policy. Therefore, in the middle and late phases of the development, it is important to integrate the policy and the market to guarantee the development of technology innovation. The valid combination of these major driving factors can create new, ecological and healthy mariculture.

5 Impacts of Mariculture on Eco-environment

Due to the increasing intensity of the exploration and utilization of marine resources as well as the expanding of mariculture, about 3.7 × 105 km^2 of the offshore area in China was reported to be contaminated to a different extent since the 1970s (Xiao et al., 2009), and mariculture was considered to be one of the major important pollution sources of offshore water contamination. In addition to destroying the balance of the offshore water environment, mariculture also posed negative impacts on the coastal wetland ecosystem that are discussed respectively as follows.

5.1 Impacts of mariculture on offshore water environment

Marine environment is polluted severely in recent years. Fig. 6 shows the area ratios of different pollutants that over standards. The influence of mariculture in the shallow sea area on the offshore water environment is mainly reflected by the increasing of pollution loads in the offshore area (Hu et al., 2007). The major pollutants from the mariculture industry are the unused feed and the excretions of the aquatic creatures (Chen et al., 2015). These pollutants will enter the offshore water in either the dissolved form or as particulates and then diffuse into the surrounding water environment (An and Zhou, 2006). This will further change the physicochemical property of the water, and even destroy the balance of the aquatic ecosystem when the pollutant loads exceed the water environment capacity.

According to the 'Bulletin of Offshore Sea Environment Quality in China, 2006–2015' (SOA, 2007–2016), the sea water in key mariculture areas were contaminated by inorganic nitrogen, active phosphate phosphorus, petroleum, and chemical oxygen demand (COD) to a different extent during the past ten years (Fig. 6). Inorganic nitrogen and phosphorus as active phosphate which originated from the unused feed and excretions were the dominant contaminants, which highly exceeded the standard rate in most of the years. In the process of traditional mariculture, increasing both the cultivation density and the amount of feed is the first way to get a high yield (Yang et al., 2003). However, the digestibility of feed by the aquatic creatures are not as high as expected, and a large amount of unused feed (usually includes dregs from soybean, peanut, colza, and cottonseeds which belong to vegetable proteins) is finally discharged into the water body together with the excretions of aquatic animals (Cai et al., 2014). For example, it has been reported that only 85% of the nitrogen consumed by shrimps was finally absorbed and assimilated, while about 15% of the nitrogen would be discharged into the water body by means of excreta (Miao et al., 2009). The excreta of aquatic animals mainly contains fat and protein (Sun, 2012), which contains the major elements of nitrogen and phosphorus. The high concentrations of nitrogen and phosphorus in sea water will cause eutrophication, which is referred to as a red tide in the ocean (Cao et al., 2007). Due to the rapid development of mariculture, the occurrence of red tides from 1980 to 1992 in China had been clearly increasing, and the frequency was about 15 times higher than that in the 1970s, causing huge economic losses (Zhu, 1999). The blooms of algae in the eutrophic water can consume the oxygen and inhibit the process of reoxygenation. The lack of oxygen, however, will cause the death of aquatic creatures (both plants and animals) and the imbalance of nutrition structure in water body, which eventually leads to a vicious circle (Isbella et al., 2013).

In order to protect the offshore water quality, the fishermen are advised to take advantage of different water space and to cultivate the filter-feeding species, omnivorous species, and predatory species hierarchically, thereby reasonably adjusting the structure of cultivation species (Wu and Fan, 2014). Under the precondition of ensuring the marine product yield, the fishermen are also suggested to optimize the feeding time, frequency and quantity according to the different eating habits of each respective aquatic animal. It is important to aim to decrease feed waste, to pay more attention to the sanitary control, to reduce the invasion of bacteria and to lower the accumulation of contaminants.

Mariculture not only caused adverse impacts on the offshore water environment, but also the expanding area occupied the wintering ground and blocked the migration pathway of some marine creatures. Most fish's feeding, wintering and breeding were moved in different regions and migration pathway was essential in the whole process (Wang, 2012).The biodiversity and the balance of the ecological system were threatened owing to the area expanding in mariculture development (Hu et al., 2007). To avoid the adverse impacts of mariculture development on the ecological system, it is important to control excessive expansion of area by implementing the regulation policy and innovating technology.

5.2 Impacts of mariculture on coastal wetland system

Based upon the coastal wetland classification system proposed by Mou et al. (2015), the natural coastal wetlands that will be discussed in the following paragraphs mainly refer to wetlands located in the supratidal and intertidal zones, as well as the shallow waters in the subtidal zone.

The traditional mariculture patterns in offshore area of China include bottom sowing culture, industrial culture,

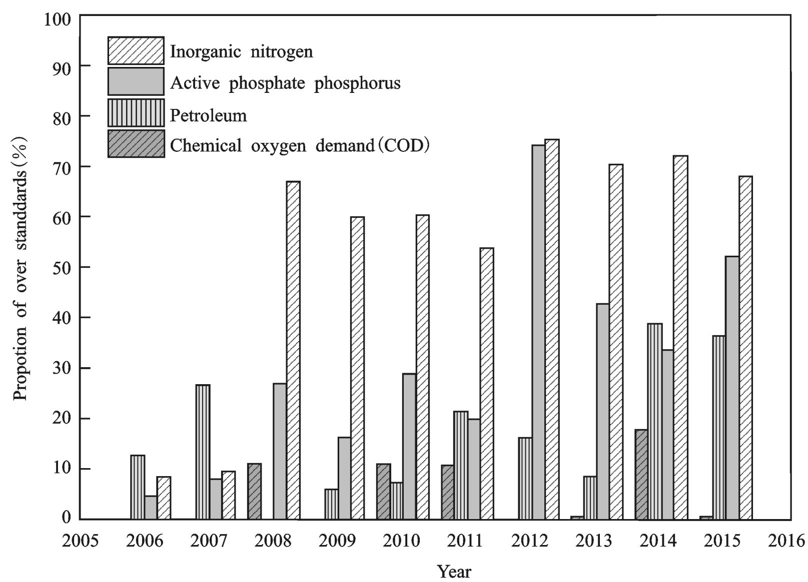

Fig. 6 Ratio of area with contaminants concentration exceeding standard levels to total monitored area from 2006 to 2015

raft culture in shallow water, and the cage culture. The cultivation activities occur in both the shallow sea and the beach (Fig. 7). The sea areas used in mariculture has become the largest type among all the other sea utilization patterns (Kang, 2011), and the mariculture area maintained a positive growth rate year by year. In recent years, the major pattern of mariculture has transferred from the bottom sowing culture to water surface culture (Wang, 2016). Correspondingly, the land reclamation in offshore area has become a major way to increase the mariculture area (Ni and Qin, 2003). China had experienced a large-scale land reclamation rush during the 20 years after the reform and opening up, and the land reclamation mainly happened in the low tide beach and the offshore area (Ma, 2009). The reclamation remarkably increased the nationwide mariculture area in China. Previous research has proved that the coastline of China had changed a lot, and some changes were result from the reclamation (Hou et al., 2016). The coastline of the Pearl River Estuary was pushed towards the ocean during 1990–2000 mainly because of the land reclamation, which was utilized for mariculture (Zhang, 2014). Similarly, the length of coastline in Liaoning Province has been increased by about 710 km during the past 30 years due to the land reclamation, which was also primarily used for constructing the seafood culture ponds (Feng et al., 2015). The land reclamation in the coastal area and the subsequent cultivation activities occurred on these reclaimed beaches, however, can destroy the natural coastal wetland systems. The tidal flat wetland and the mangrove wetland are two major types of wetlands that have been developed and/or utilized. The tidal flat wetland ecosystems provide not only spawning and breeding sites for many creatures, but also habitats for many wildlife (Hu et al., 2016). Mangrove wetland is one type of subtropical and tropical wetland systems that exists in the transitional zone between ocean and continent. Mangrove wetlands can also provide spawning and foraging sites for many marine creatures, and it has the function of resisting the wind and waves, and purifying the water emptying into the ocean (Stokes et al., 2016; Ni and Qin, 2003). Mudflat aquaculture is the most important portion of the current cultivation patterns in China (Lei, 2010). In order to obtain higher seafood yields, the scale of mudflat aquaculture has been expanded blindly, and the area of both tidal flat wetland and the mangrove wetland have been decreased, as the seafood (e.g., shrimp) culture ponds were sometimes directly developed within the wetland system (Yu, 2008). For example, remote sensing data proved that the area of tidal flat wetland in the Kiaochow Bay has decreased from 9607.68 ha in 1986 to 5897.27 ha in 2010, while, the area of culture ponds has increased from 951.48 ha in 1986 to 5198.27 ha in 2010 (Zhang et al., 2012). During the past 40 years, the area of mangrove wetland in China has reduced from about 4.9×10^4 ha to 3.2×10^4 ha, which was mainly driven by human activities like culture ponds development and its associated land reclamation, as well as the deforestation (Jia, 2014). Currently, a big portion of the shallow sea bench-land in China has been developed and utilized for constructing shrimp and crab culture ponds, which has not only destroyed the ecological landscape of the nature wetlands, but also lead to a potential threat to the endangered wild animals and plants which live in the wetland systems. With the decrease of coastal wetland area, the function of wetlands which is described as 'kidney of the earth' would gradually decrease. Both tidal flat wetland and mangrove wetland are fragile ecosystems, and the restoration of degraded wetlands requires huge costs and faces technical challenges (Yang et al., 2006).

Apart from occupying the area of coastal wetlands, the mariculture can also pose serious contamination to the wetlands by discharging the wastewater into the wetland systems. Because of the increasing cultivation intensity, the amount of wastewater from aquaculture will consequently increase. The natural balance of a wetland system will be easily destroyed once the pollution load exceeds the self-purification capacity of the

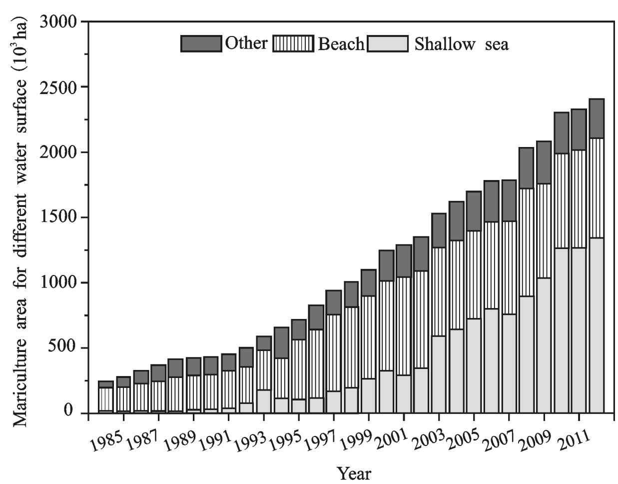

Fig. 7 Mariculture area in different locations from 1985 to 2012

wetland, which will further bring more negative effects.

The 21st century is an important period for deepening the reform in the field of ecological environmental protection. Both 'Twelfth' and 'Thirteenth' Five-Year Plan in China has developed a series of policy systems regarding the environmental protection. The latest announced 'Thirteenth Five-Year Plan' has proposed to implement the most strict environmental protection system. The 'Guidelines on the adjustment of key industrial distribution and industrial transfer' released by both Central Committee of the Party and the State Council emphasizes to implement the marine main function planning, to vigorously promote the marine ecological civilization construction, to improve the marine technical innovation and supporting capacity, to push forward the ecological seafood culture, and to control the chemical contamination loads. Therefore, it is necessary and important to reasonably control the cultivation density, to efficiently utilize the available cultivation area, and to reduce the environmental pollution. Under the latest guidelines of the government, the impacts of mariculture on the eco-environment are supposed to be controlled and improved in the near future.

6 Conclusions

The mariculture in China has been continuously and constantly developed during the past 40 years since the reform and opening up, which mainly reflects the increasing in the mariculture area and the diversification of cultivation species. However, driven by both the policy and market, the development characteristics of mariculture differed among different development phases and different provinces. For the nationwide mariculture area, it showed a rapid development from 1979 to 1988 and a relatively stable development since the year of 1998. The major cultivation species were shellfish and algae at the beginning and have been developed to shellfish and crustacean dominant multiple species recently. Accompanying the development of mariculture, its associated eco-environment problems like the contamination of waters in the mariculture area and its surrounding environment, and the shrinking of coastal wetland systems as well as the degradation of wetlands function are gradually increasing. The reasonable control of the cultivation density, the efficient utilization of the available cultivation area, and the reduction of environmental pollution should be highlighted and implemented.

References

An Xinlong, Zhou Qixing, 2006. Progress in study of bioremediation for aquaculture self-polluted water bodies. *Techniques and Equipment for Environmental Pollution Control*, 7(9): 1–6. (in Chinese)

Cai Huiwen, Zhuo Lifei, Wu Changwen, 2014. Review of waste loadings generation from marine aquaculture. *Journal of Zhejiang Ocean University* (*Natural Science*), 33(6): 558–567. (in Chinese)

Cao L, Naylor R, Henriksson P et al., 2015. China's aquaculture and the world's wild fisheries. *Science*, 347(6218): 133–135. doi: 10.1126/science.1260149

Cao L, Wang W M, Yang Y et al., 2007. Environmental impact of aquaculture and countermeasures to aquaculture pollution in China. *Environmental Science and Pollution Research*, 14(7): 452–462. doi: 10.1065/espr.2007.05.426

Chen H, Liu S, Xu X R et al., 2015. Antibiotics in typical marine aquaculture farms surrounding Hailing Island, South China: Occurrence, bioaccumulation and human dietary exposure. *Marine Pollution Bulletin*, 90(1–2): 181–187. doi: 10.1016/j.marpolbul.2014.10.053

Chen Mingbao, Han Limin, 2016.Driving factors, areas of cooperation and mechanisms for international cooperation in the blue economy of the 21st-Century Maritime Silk Road. *Engineering Sciences*, 18(2): 98–104. (in Chinese)

Chen Xiuguo, 2008. A preliminary analysis on the effect of marine aquaculture on water environment and its prevention measures. *Modern Agricultural Sciences*, 15(11): 111–112. (in Chinese)

Cheng Jincheng, Liu Jian, Gao Jian, 2005. Chinese fishery policy change and its role in the balance of the future aquatic products. C*hinese Fisheries Economics*, (3): 30–32. (in Chinese)

Fan Jianyong, Huang Haijun, Fan Hui et al., 2005. Extracting aquaculture area with RADASAT1. *Marine Sciences*, 29(10): 46–49. (in Chinese)

Feng Yongjiu, Yuan Jiayu, Song Lijun et al., 2015. Coastline mapping and change direction along Hangzhou Bay using remotely sensed imagery. *Remote Sensing Technology and Application*, 30(2): 345–352. (in Chinese)

Hou X Y, Wu T, Hou W et al., 2016. Characteristics of coastline changes in mainland China since the early 1940s. *Science China* (*Earth Sciences*), 59(9): 1791–1802. doi: 10.1007/s11430-016-5317-5

Hu Wenjia, Yang Shengyun, Zhu Xiaoming, 2007. The impact of mariculture on the marine ecosystem and studies on bioremediation. *Journal of Xiamen University* (*Natural Science*), 46(S.1): 197–202. (in Chinese)

Hu Y, Wang L, Fu X H et al., 2016. Salinity and nutrient contents of tidal water affects soil respiration and carbon sequestration of high and low tidal flats of Jiuduansha wetlands in different ways. *Science of the Total Environment*, 565: 637–648. doi: 10.1016/j.scitotenv.2016.05.004

Isbella F, Reichb P B, Tilman D et al., 2013. Nutrient enrichment, biodiversity loss, and consequent declines in ecosystem productivity. *Proceedings of the National Academy of Sciences of the United States of America*, 110(29): 11911–11916. doi: 10.1073/pnas.1310880110

JiaMingming, 2014. *Remote Sensing Analysis of China's Mangrove Forests Dynamics During 1973 to 2013*. Changchun: Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, 1–2. (in Chinese)

Kang Weiwei, 2011. *The Impact Study of Mariculture on Marine Ecology Environment in Changli*, *Hebei Province*. Shijiazhuang: Hebei Normal University, 1–3. (in Chinese)

Lei Jilin, 2010. Strategy consideration for industry construction of Chinese marine culture. *Journal of Fishery Sciences of China*, 17(3): 600–609. (in Chinese)

Lei Yanju, 2014. *The Toxicity Effects of Copper and Cadmium and the Possible Protective Effects of Selenium and α-lipoic Acid on juvenile abalone Haliotis discus hannaiIno*. Qingdao: Ocean University of China, 4–6. (in Chinese)

Li Chunhou, Wang Xuefeng, Wang Xiaowei et al., 2006. Water quality for mariculture and its ecological rehabilitation technology. *Journal of Agro-Environment Science*, 25(S.): 310–315. (in Chinese)

Li Dahai, Pan Kehou, Chen Lingling, 2008. Evolution and development of saltwater aquaculture policy since the reform in China. *Chinese Fisheries Economics*, 26(3): 57–61. (in Chinese)

Li Huitao, 2004. *The Effects of Dietary Poisonous or Deleterious Substances on Growth and Its Residues in Tissues of Japanese seabass*, *Lateolabrax Japonicus and Large Yellow Croaker*, *Poseudosciaena Crocea*. Qingdao: Ocean University of China, 2–10. (in Chinese)

Li X P, Li J R, Wang Y P et al., 2011. Aquaculture industry in China: current state, challenges and outlook. *Reviews in Fisheries Science*, 19(3): 187–200. doi: 10.1080/10641262.2011.573597

Liang P, Wu S C, Zhang J et al., 2016. The effects of mariculture on heavy metal distribution in sediments and cultured fish around the Pearl River Delta region, south China. *Chemosphere*, 148: 171–177. doi: 10.1016/j.chemosphere.2015.10.110

Ma Jun, 2009. *Study on Marine Environmental Impact of Land Reclamation from Sea in Dalian City* (*Take the Project in Xiaoyao Bay for Example*). Dalian: Dalian Maritime University, 5–6. (in Chinese)

MAC (Ministry of Agriculture of the People's Republic of China), 1979–2012. *Chinese Fishery Statistical Yearbook*, *1980–2013*. Beijing: China Agriculture Press. (in Chinese)

MEPC (Ministry of Environmental Protection of the People's Republic of China), 2015.*China's Environment Quality Bulletin*, *201 6*. http://www.mep.gov.cn/hjzl/zghjzkgb/lnzghjzkgb/

Miao Shuyan, Wang Jiying, Zhang Limin et al, 2009.The impacts of aquatic animals'bait and waste on aquaculture environment. *Feed Research*, (2): 64–67. (in Chinese)

Mou Xiaojie, Liu Xingtu, Yan Baixing et al., 2015. Classification system of coastal wetlands in China. *Wetland Science*, 13(1): 19–26. (in Chinese)

Ni Jinren, Qin Huapeng, 2003. Assessment of reclamation impact on inter-tidal habitat loss.*Acta Scientiae Circumstantiae*, 23(3): 345–349. (in Chinese)

SOA (State Oceanic Administration, People's Republic of China), 2006–2015.*China's Marine Environmental quality Bulletin*, 2007-2016. http://www.soa.gov.cn/

Song Liqing, 2007.*Research on Transferring Coastal Fishermen in China*. Qingdao: Ocean University of China, 123–125. (in Chinese)

Song Xiangrong, Yu Jie, GengXuyun et al., 2016. The development strategy of mariculture industries in Tianjin. *Hebei Fisheries*, 5: 74–76. (in Chinese)

Stokes D J, Bulmer R H, Lundquist C J, 2016. Addressing the mismatch between restoration objectives and monitoring needs to support mangrove management. *Ocean & Coastal Management*, 134: 69–78. doi: 10.1016/j.ocecoaman.2016.09.024

Sun Jiting, Zhao Yujie, 2011. The whole mechanism of sea and land in the development of our country's Marine economy.*Social Science in Guangdong*, (5): 41–47. (in Chinese)

Sun Zhenlong, 2012. *Study on the Main Nutrient Metabolism of the Farming Sea Cucumber*. Qingdao: Ocean University of China, 4–7. (in Chinese)

Wang Chengyou, 2012. *Migrations for reproduction of Chinese Sturgeon (Acipenser sinensis) and its habitat selections in the Yangze River*. Wuhan: Huazhong Agricultural University, 12–13. (in Chinese)

Wang Jinhuan, 2016. Study on marine aquaculture modes under the constraint of resource and environment. *Chinese Fisheries Economics*, 34 (6): 76–82. (in Chinese)

Wang Yongli, Yu Junbao, Dong Hongfang et al., 2012.Spatial Evolution of landscape pattern of coastal wetlands in Yellow River Delta. *Scientia Geographica Sinica*, 32(6): 717–724. (in Chinese)

Wu Wei, Fan Limin, 2014. Pollution and control measures of aquaculture environment. *Journal of Agricultural Science and Technology*, 16(2): 26–34. (in Chinese)

Xiao Changti, Zhang Shuying, Chen Haijun, 2009. Primary analysis on effect of mariculture on coastal water Environment. *Modern Fisheries Information*, 24(9): 9–10. (in Chinese)

Yang Lei, Shu Tingfei, Wen Yanmao, 2003. Countermeasures on sustainble development of mariculture in China. *Fisheries Science*, 22(4): 45–48. (in Chinese)

Yang Ningsheng, 2006. Scientific & technical innovation and fishery development. *Chinese Fisheries Economics*, 3: 8–11. (in Chinese)

Yang Weihua, Gao Huiwang, Zhang Yongju, 2006. Progress in studies on the impact of mariculture on the coastal environment. *Transactions of Oceanology and Limnology*, (1): 100–107. (in Chinese)

Yao Shujing, 2015.*Research on Technology Innovation Driving Force of China's Traditional Marine Advantageous Industry*. Qingdao: Ocean University of China, 1–3. (in Chinese)

Yuwen Qing, 2008. Discussion of impacts of mariculture on the Marine environment. *Ocean Development and Management*, (12): 113–117. (in Chinese)

Zhang Xuling, Zhang Zhaohui, Xu Zongjun et al., 2012. Landscape pattern changes and their environmental effects of coastal wetlands in Jiaozhou Bay. *Geological Review*, 58(1): 190–200. (in Chinese)

Zhang Yi, 2014. *Analyzing Shoreline Changes of the Pearl River Estuary Based on Remote Sensing in Recent Forty Years*. Huhhot: Inner Mongolia Normal University, 2–3. (in Chinese)

Zhao Huifang, 2013. *The Marine Fisheries Evolutionary Mechanism Study of China*. Qingdao: Ocean University of China, 29–32 (in Chinese)

Zhu Huasheng, 1999. China's coastal waters pollution and mariculture. *Territory & Natural Resources Study*, 4(1): 12–14. (in Chinese)

Zuo Ping, Li Yun, Zhao Shuhe et al., 2012. Landscape changes of Jiangsu Yancheng coastal wetlands and their driving forces since 1976. *Acta Oceanologica Sinica*, 34(1): 101–108. (in Chinese)