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Current Situation and Sustainable Development Strategies of China's Fishery Environment

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Abstract: The survival and reproduction of aquatic organisms rely on a healthy fishery environment, which is also the foundation of fishery development. In general, the deterioration of the environmental quality of fishery waters in China has not yet been completely addressed, and dissolved inorganic nitrogen and active phosphate are still the major indicators of pollution in fishery waters. Based on the analysis of the status and variation trend of the fisheries environment, in this review we present the main factors that affect the sustainable development of China's fisheries environment, including the development of construction projects, exogenous pollution, ecological disasters, and pollution accidents. Additionally, this review identifies major fishery resources and environmental issues in key areas of the aquatic environment, and proposes ideas, goals, measures, and recommendations regarding the sustainable development of the fishery environment in China. The study also provides references for the protection and management of China's fishery environment.
Key words: fishery environment; sustainable development; environmental quality; strategic planning

1 Introduction

China is a fishery superpower. In 2017, the total aquatic production of China reached 6.901×10^7 t (accounting for more than one-third of the world's total aquatic production). The fishery production value reached 1.200291 trillion yuan, per capita net income of fishermen reached 16 904.20 yuan, per capita consumption of aquatic products reached 49.91 kg, and the import and export volumes of aquatic products reached 30.112 billion USD. Fisheries have made important contributions to safeguarding national food security and promoting the increase of income of farmers and fishermen. China is also the world's largest aquaculture producer, accounting for more than 70% of the world's total aquaculture production. According to the *China Fishery Statistics Yearbook*, in 2017, China's aquaculture production was 5.142×10^7 t, and aquaculture products accounted for 74.51% of the total aquatic products, of which mariculture production was 1.963×10^7 t. The total area used for aquaculture was 8.346×10^6 hm^2, of which the area used for

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mariculture was 2.167×10^6 hm^2. After years of development, China's aquaculture industry is now playing a pivotal role in the development of national economy. Since entering the 21st century, China has firmly established the concept of green development, and has vigorously promoted the construction of ecological fisheries as the only way to develop them sustainably. In this study, based on the analysis of the status and evolutionary trend of the fishery environment, we recount the main factors for the sustainable development of the fishery environment, identify major fishery resources and environmental issues in China's key aquatic areas, and propose ideas, goals, measures, and recommendations for the sustainable development of the fishery environment in China. The study also provides references for the protection and management of fishery environments in China.

2 Current situation and challenges facing the sustainable development of the fishery environment

2.1 Exogenous pollution sources seriously affect the environmental quality of fishery waters

According to the 2016 *Bulletin of Marine Environment Conditions in China Sea*, the over-limit rates of inorganic nitrogen, labile phosphates, petroleum, and chemical oxygen demand (COD) of important natural marine fishery waters were 85.1%, 61.8%, 5.2%, and 23.6%, respectively. Inorganic nitrogen and labile phosphates were the major pollution indicators. The over-limit rates of total nitrogen, total phosphorus, non-ion ammonia, potassium permanganate index, petroleum, volatile phenol, and copper in important natural river fishery waters were 99.0%, 52.6%, 6.2%, 24.1%, 0.7%, 2.2%, and 2.6%, respectively, among which the over-limit rates of the total nitrogen and total phosphorus were highest. The rates of total nitrogen, total phosphorus, non-ion ammonia, potassium permanganate index, petroleum, volatile phenol, and copper in important fishery waters of lakes and reservoirs were 96.6%, 87.0%, 64.6%, 8.6%, 0.4%, and 13.9%, respectively, among which the over-limit rates of the total nitrogen, total phosphorus, and potassium permanganate index were highest [1]. Exogenous pollutants in the fishery environment are mainly nitrogen, phosphorus, COD, petroleum, and heavy metals, with land-based emissions as the major sources of pollution. Taking the pollutants that have entered the sea as an example, the *2016 Bulletin of Marine Environment Conditions in China Sea* indicated that the discharges of pollutants from 61 rivers across the country to the sea were as follows: COD_{Cr}, 1.372×10^7 t; ammonia nitrogen, 1.9×10^5 t; nitrate nitrogen, 2.27×10^6 t; total phosphorus, 1.8×10^5 t; petroleum, 4.6×10^4 t; and heavy metals, 1.4×10^4 t.

2.2 Ecological disasters and pollution accidents cause serious economic losses

In 2015, a total of 35 red tides were noticed in China's jurisdiction over the sea area, with a total cumulative area of approximately 2 809 km^2. 2015 was the year with the least number of red tides and smallest accumulated area within the last 5 years; compared with the average of the past 5 years, the number of reported red tides declined by 18, and the cumulative area declined by 2 835 km^2. In recent years, frequent outbreaks of green tides (formed by *Enteromorpha*) occurred in China's coastal areas, posing serious threats to coast and natural fisheries. The frequency and affected area due to outbreaks of freshwater harmful algal blooms in China have not significantly decreased in recent years. Table 1 shows the number of fishery pollution accidents and economic losses from 1999 to 2016. In 2016, a total of 68 pollution accidents in fishery waters occurred in China, resulting in direct economic losses of 23 million yuan, even though it was the year with the least number of fishery pollution accidents and lowest economic losses since 1999. In short, despite the reduction in the number of fishery pollution accidents and the resultant economic losses, the losses caused by major fishery pollution accidents are still substantial.

2.3 Development of construction projects invades fishery waters

The impact of the development of construction projects mainly has two aspects. First, development affects the area of the fishery waters, causing habitat loss for fish eggs, larvae, fishes, benthos, and plankton. Second, it alters the biological, chemical, and physical environment of the fishery waters and further affects the growth, development, and reproduction of the fishery organisms. In the Bohai Sea, for example, according to the statistics of the State Oceanic Administration, the sea use area with confirmed rights for Shandong, Hebei, Liaoning, and Tianjin Provinces increased from 8.4×10^4 hm^2 in 2002 to 2.75×10^5 hm^2 in 2013, and the proportion in the national sea use area increased from 37.8% to 78.6%.

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Table 1. Fishery pollution accident statistics from 1999−2016.

Year	Ocean		Inland		Total	
	Number of fishery pollution accidents	Economic loss due to fisheries pollution (hundred million yuan)	Number of fishery pollution accidents	Fisheries pollution loss (hundred million yuan)	Number of fishery pollution accidents	Economic loss due to fisheries pollution (hundred million yuan)
1999	104	2.700	843	2.300	947	5.000
2000	120	3.000	1000	2.600	11 20	5.600
2001	35	1.900	1207	1.600	1242	3.500
2002	63	2.320	1192	1.560	1255	3.880
2003	80	5.800	1194	1.330	1274	7.130
2004	79	8.900	941	1.900	1020	10.800
2005	91	4.030	937	2.370	1028	6.400
2006	87	1.380	1376	1.160	1463	2.540
2007	73	1.310	1369	1.670	1442	2.980
2008	88	0.368	937	1.280	1025	1.648
2009	50	0.879	999	0.996	1049	1.875
2010	21	2.000	912	1.820	933	3.820
2011	/	/	/	/	680	3.680
2012	/	/	/	/	424	1.612
2013	/	/	/	/	343	2.400
2014	/	/	/	/	284	0.531
2015	/	/	/	/	79	1.640
2016	3	0.120	65	0.110	68	0.230

2.4 Aquaculture pollution has negative impacts on the environmental quality of waters

On the one hand, aquaculture can reduce CO_2 emissions, ease the eutrophication of waters, and promote the development of green and low-carbon fisheries. Cleaning organisms such as filter-feeding shellfish, certain echinoderms, phytoplankton, and macroalgae can sequester nutrients from aquaculture waters and convert them into valuable products. In 2014, China's marine seaweed and shellfish farming was estimated to have sequestered 1.68×10^6 t of carbon from coastal seas, while freshwater filter-feeding fish farming had sequestered approximately 1.6×10^6 t of carbon from inland waters, with the total contribution to the reduction in atmospheric CO_2 being equivalent to more than 1.2×10^6 hm^2 afforestation each year [2]. On the other hand, the discharge of pollutants such as nitrogen and phosphorus in aquaculture is an important nonpoint source pollution. During the aquaculture process, large amounts of feeds and fishery drugs must be added to the water. Except for the portion that is absorbed by the cultured organisms, the feed reside, excrement, carcasses of aquatic organisms, fishery nutrients, and fishery drugs in the aquaculture water greatly increase, resulting in the amounts of nitrogen, phosphorus, fishery medicines, and other organic and inorganic substances that exceed the self-purification capacity of the water bodies and cause pollution to the water environment after discharge. Studies have shown that under the current feeding regime, 80% of the feed is consumed by fish, of which only 20% is utilized for fish weight gain, and 60% is excreted as feces. The remaining 20% is directly discharged into the water environment as feed residue. Due to the unsound quality assurance system of aquaculture products and the inadequate quality awareness of aquaculture producers, problems resulting from illegal use of banned chemicals such as malachite green, nitrofuran, and chloramphenicol in the breeding process are severe. This uses results in serious issues from over-limit levels of residuals from drugs and harmful substances. In recent years, China's export of aquatic products has been restricted multiple times by the European Union, Japan, and other countries and regions due to quality problems. Incidents such as the "turbot incident" and the "Yangtze River poisonous fish incident" have seriously affected the quality and safety of aquatic products. Overall, the proportion of pollution load of aquaculture has been relatively small, but in some bays, lakes, and reservoirs, aquaculture can be a major source of environmental pollution (Table 2) [3−18], the causes of which are closely related to the conditions of hydrodynamic exchange, production method, and farming pattern in local waters.

Table 2. Ratio of pollution load of aquaculture in different water areas over total pollution load.

Fishery waters category	Fishery waters	Statistical year	Ratio of aquaculture pollution load over total pollution load			Reference
			Total N	Total P	COD	
Ocean areas	Yellow Sea and Bohai Sea	2002	2.8%	5.3%	1.8%	[3]
	Jiaozhou Bay	1998−2005	Dissolved inorganic nitrogen <1%	Phosphates ~2%	3%	[4]
	Bohai Sea	1980−2005	Dissolved inorganic nitrogen ~4%	7%	11%	[4]
	Bohai Sea	1979−2005	Dissolved inorganic nitrogen 1.4%	1.1%	3.0%	[5]
Rivers and lakes	Tongan Bay in Xiamen	2000/2004	12.3%/35.0%	15.7%/32.7%	11.9%/20.1%	[6]
	West Sea area and Tongan Bay in Xiamen	2008	0.3%	0.5%	1.0%	[7]
	Hangzhou Bay	2008	1.5%	0.6%	2.3%	[8]
	Liaohe River source area	1999–2009	0.1%	0.1%	0.3%	[9]
	Pengxihe River Basin, Three Gorges Reservoir area	2008	1.7%	/	0.7%	[10]
	Suzhou River	1999−2000	7.0% ammonia nitrogen: 2.0%	2.8%	6.6%	[11]
	East Dongting Lake	2010	2.3%	0.9%	6.9%	[12]
	Tai Lake	2008	9.0%	13.0%	4.0%	[13]
	Tai Lake (Suzhou area)	2011	23.0%	/	/	[14]
	Honghu Lake Basin	2010	43.7% (Ammonia nitrogen: 44.3%)	26.1%	13.8%	[15]
	Taiping Lake, Anhui Province	2011	Ammonia nitrogen: 0.9%	4.8%	3.8%	[16]
Reservoir	Upstream of the Huairou Reservoir	2000−2011	17.2%	21.0%	/	[17]
	Shanxi Hutang Reservoir	2012	10.0%	3.5%	2.4%	[18]

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3 Identification of fishery resources and environmental issues in key waters

3.1 Bohai Sea

Many rivers of various sizes lie along the coast of the Bohai Sea with fertile water and rich food resources, providing ideal spawning and feeding grounds for a variety of economically valuable fish and shrimp species in the Yellow Sea and the Bohai Sea. These rivers play extremely important roles in the fishery production in the two seas [19]. Bohai Sea fishery resources are at risk, dwindling from 75 species in 1982 to a little more than 30 species in 2009. Of the remaining species, most are small-sized pelagic and mesopelagic fish species. Traditional commercial fish species, such as the saury (*Coilia ectenes*), small yellow croaker (*Pseudosciaena polyactis*), and sea bream (*Pagrosomus major*) are becoming endangered. Additionally, the populations of Spanish mackerel (*Scomberomorus niphonius*), croaker (*Nibea albiflor*), sea bass (*Lateolabrax japonicus*), pomfret (*Pampus argenteus*), and a few others, are also declining. The benthonic biological resources in the Bohai Sea are currently only one tenth of those in the 1950s. China's annual catches of shrimp in 1983, 1992, and 1998 were 1.43×10^4 t, 0.49×10^4 t, and 0.17×10^4 t, respectively, with an obvious downward trend.

The coastal waters of the Bohai Sea are heavily polluted. The eutrophic sea areas are primarily concentrated in the near-shore regions of Liaodong Bay, Bohai Bay, and Laizhou Bay. The sea area with a water quality category of Grade IV or worse is 1.142×10^4 km^2, accounting for approximately 15% of the total area of the Bohai Sea. The major over-limit pollutants are inorganic nitrogen, labile phosphates, and petroleum. From 2006 to 2013, the pollution of the coastal waters of the Bohai Sea largely increased, and the sea area that does not meet the water quality standards for Grade I seawater increased from 2.008×10^4 km^2 to 3.34×10^4 km^2, of which the area with a seawater quality worse than Grade IV increased from 2 770 km^2 to 8 490 km^2 [3]. The high volume of discharge from inland pollution sources, frequent development activities regarding sea area reclamation, and frequent occurrence of marine environmental disasters are important factors affecting the fishery resources and ecological environment of the Bohai Sea.

3.2 Yangtze River Basin

The Yangtze River is the cradle of China's freshwater fishery, the treasure house of fish genes, the elite species base of economic fish, and a typical representative of biodiversity. Since 1961, due to large-scale development of water conservation projects, rivers and lakes in the Yangtze River Basin have become increasingly isolated, whereas a large number of reclamations in the lake areas has led to rapid decrease in the areas of the rivers and lakes. These and other factors such as over fishing and pollution have contributed to a decline in the output of fishery resources. The average annual production from 1961 to 1978 was only 2.377×10^5 t. In the 1980s, the average annual fish production fluctuated, with an average of approximately 2×10^5 t, but decreased by nearly 50% in the 1990s; in 2011, the catches decreased to less than 1×10^5 t. In particular, fish resources in the Yangtze River Estuary, such as the bigmouth grenadier anchovy (*Coilia nasus*) and the Tapertail anchovy (*Coilia mystus*), have declined drastically.

The largest direct impact of human activities on the basin system has been from water conservancy projects such as damming and water diversion. According to statistics, 44 000 reservoirs had been built in the Yangtze River Basin by 2000. Currently, the mainstream water quality of the Yangtze River is generally good, but the environmental capacity in some local areas has approached or reached the critical point of development. Some areas where the mainstream of the Yangtze River intersects some cities have been extensively polluted. As of 2012, the cross-sections with water quality categories of Grade IV, Grade V, or worse than Grade V in the Yangtze River mainstream accounted for only 13.8% of the total sections monitored, but this percentage is higher than that observed in 2004 (5.7%) [20].

3.3 Zhoushan Fishery

Fishery resources in the Zhoushan Fishery have experienced a serious decline, manifested as sharp declines in the yield and proportion of economic fish species, especially the four major domestic fish species that once dominated traditional catches of Zhoushan Fishery. The proportion they contributed to total catches has decreased from 76.96% in 1974 to 36.06% in 1984, 1.13% in 2008, and less than 1% in 2015. The catch per unit area of major economic fish resources has been declining year by year, from 3 t/kW during the abundance of the resources to less than 0.5 t/kW currently—a historical low. At the same time, the catch species have gradually become lower in value and smaller in size, indicating a downward trend in the average trophic level of fishing catches. The large amount of waste water, waste gas, and solid waste generated from the vigorous economic development in the Yangtze River Delta have also entered the sea area of the Zhoushan Fishery in different ways, such as runoff. In recent years, the water quality of the Zhoushan Fishery has been generally worse than Grade IV. Meanwhile, the reclamation on the coastal tidal flats and bays is gradually scaling up.

3.4 Poyang Lake

Poyang Lake is China's largest freshwater lake, and is rich in fishery resources. Surveys show that the catch and catch composition of Poyang Lake have changed dramatically since the 1980s, with the catches being dominated by nonmigratory fish species, such as common carp (*Cyprinus carpio*), crucian carp (*Carassius auratus*), catfish (*Silurus asotus*), and yellow catfish (*Pelteobagrus fulvidraco*), accounting for more than 90% of the total species. The proportion of the four major domestic fish species in the catches having dropped to 6.4% or even lower. Migratory fish species such as *Coilia ectenes* have become increasingly rare, and the yield of the catches, which tend to be younger, smaller, and of lower quality, has decreased year by year. Large-scale reclamations have shrunk the Poyang Lake wetland area by 1 203 km^2 and have blocked the passages to many spawning grounds. This has reduced the area of good spawning grounds for common carp and crucian carp from 5.2×10^4 hm^2 in the 1960s to less than 2.6×10^4 hm^2 in 2007 [21].

4 Sustainable development strategy for the fishery environment

4.1 Development ideas

Ideas for enhancing China's sustainable fishery development include following a green, low-carbon, and environmentally friendly development path, using the driving force of innovation to push further development, updating the development concept, altering the development mode, expanding the development space, improving the quality of development, promoting the coordination of the country's major needs and sustainable development, and promoting the modernization of fisheries.

4.2 Planning objectives

The overall goal is to take a green, low-carbon, and environmentally friendly development path to achieve the objective of fishery environment protection and resource conservation by curbing the deterioration of the fishery environment. This includes gradually improving, restoring, and conserving the fishery ecological environment, and rationally developing and utilizing the functions of the ecological environment of the fishery waters to provide good basic conditions and solid guarantees for the healthy, stable, and sustainable development of fisheries in China.

Specific objectives of sustainable fishery environment development by 2025 are as follows, the ecological environment of important fishery waters will be gradually restored, the environmental quality of fisheries will be fundamentally improved, the over-limit rates of major pollutants (inorganic nitrogen, labile phosphate, and petroleum) recorded at the monitoring stations will be reduced to below 50%, the fishery environment monitoring capabilities will be significantly strengthened, and the key core technologies for aquaculture environmental monitoring, assessment, and rehabilitation will reach the international advanced level. By 2030, the ecological environmental quality of important fishery waters will be significantly improved, the monitoring station over-limit rates of the major pollutants (inorganic nitrogen, labile phosphate, and petroleum) will be reduced to below 10%, the fishery environment biodiversity will be effectively protected, the overall fishery ecosystem will be in excellent condition, sustainable fishery resources utilization will be achieved, a sophisticated and complete fishery environment monitoring and disaster warning network system will be established, and the key core technologies for aquaculture environmental monitoring, assessment, and rehabilitation will reach the level of an international leader.

4.3 Measures and recommendations

4.3.1 Strictly controlling external pollution in fishery waters

The land-based pollutant threshold control system should be implemented, so that the discharges of industrial wastewater, domestic sewage, and agricultural nonpoint source pollution to fishery waters can be strictly regulated, and the impact of external pollution on the fishery environment can be gradually mitigated.

4.3.2 Rationally planning the aquaculture layout to reduce aquaculture pollution

The regional layout of aquaculture should be rationally planned according to the environmental capacity and aquaculture capacity to vigorously develop a healthy, ecological, sustainable, and carbon-sequestrating fishery production model. In the absence of national standards for aquaculture wastewater discharge, its discharge is unregulated. Therefore, the issue of wastewater discharge in the aquaculture industry urgently needs the attention of the relevant government agencies.

4.3.3 Drawing the fishery ecological red line

Based on the importance, sensitivity, and vulnerability of fishery resources and environment, important fishery waters, such as the national aquatic germplasm resources protection zones and "the 'three grounds' and 'one route'" (spawning ground, feeding ground, wintering ground, and migration route), should all be included in the red line area so that the strict "fishery ecological red line" protection system can be implemented. The minimum use area of aquaculture waters should be set above 9×10^6 hm^2.

4.3.4 Strengthening long-term and basic monitoring of the fishery resources and environment

We should strive to establish a complete and sophisticated technical system for monitoring the fishery ecological environment by focusing on various problems in China's fishery resources and environmental monitoring. These problems include, incomplete monitoring network, non-systematic monitoring index system, unsophisticated monitoring-related laws and regulations, lack of emergency-coping and early-warning capabilities, underdeveloped key monitoring technologies, and inadequate monitoring levels.

4.3.5 Strengthening the conservation and environmental restoration of inland and offshore fishery resources

Through various measures, including the development of artificial reefs, artificial propagation, and the release of fisheries species, fisheries conservation and environmental restoration can be strengthened to achieve coordinated development of resources, environmental protection, and economy.

4.3.6 Implementing major fisheries innovation projects

Various projects should be implemented to promote the transformation and upgradation of fisheries, the construction of ecological civilization, the implementation of the strategy to empower the nation through fishery production, and the strategy of "One Belt and One Road" to ensure the sustainable development of national rights and fisheries. These projects could include the concepts of intelligent fishery environmental monitoring, assessment and early warning, new pollutant identification and control, upgrading energy-conserving and environmental-protective aquaculture modes, function restoration and reconstruction of damaged ecosystems, offshore marine ranch construction and sustainable use of biological resources, integration and demonstration of ecological environmental regulation and rehabilitation technologies for proliferation and culture of fisheries species, integration and demonstration of emergency monitoring and biological resources damage assessment technologies for fishery pollution accidents and ecological disasters, and resource conservation, environmental restoration.

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