

# Spatio-temporal Evolution of Marine Fishery Industry Ecosystem Vulnerability in the Bohai Rim Region

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**Abstract:** The building of the ocean power strategy and the implementation of the blue agriculture plan urgently need to strengthen the sustainable development of marine fishery. Taking vulnerability as the starting point, this paper constructs the vulnerability index system of marine fishery industry ecosystem from the aspects of sensitivity and response capacity, and combines the entropy method with the Topsis to comprehensively analyze the spatio-temporal evolution characteristics of vulnerability of marine fishery industry ecosystem in the Bohai Rim Region from 2001 to 2015. The results show that: 1) In the time dimension, from 2001 to 2015, the vulnerability of the marine fishery industry ecosystem in the Bohai Rim Region shows a fluctuant and degressive trend; 2) In the spatial dimension, the spatial distribution of the marine fishery industry ecosystem vulnerability in the Bohai Rim Region presents the gradient characteristics which shows high vulnerability in the east and low vulnerability in the west. According to the evolution track of the system's vulnerability level, the vulnerability of the marine fishery industry ecosystem is divided into 'declining' and 'stable' types of evolutionary structures; 3) The development of marine fishery in the Bohai Rim Region needs to be derived from the marine fishery's ecological environment and the industrial development mode and structure, which can improve the marine environment remediation efforts, optimize the marine fishery industry structure, vigorously focus on pelagic fishery, and enhance the introduction of marine fishery's science and technology talents, etc. Then, the marine fishery's development in the Bohai Rim Region will be moving in the green, circular and sustainable direction.

**Keywords:** marine fishery; marine industry ecosystem; vulnerability; spatio-temporal evolution; Bohai Rim Region

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## 1 Introduction

Along with the strategy of ocean power in the 13th Five-Year Development Plan, the development of the marine economy has become an important support of driving the whole country's economy development. Meanwhile, the marine fishery as a pivotal role for blue agriculture is the foundation for the development of the marine economy. China relies on 7% of cultivated land to feed 22% of the population. Under the scope of large-scale agriculture, China's terrestrial agriculture has

already reached saturation point to a certain extent, thereby moving its development goals in marine, then developing marine agriculture has become a breakthrough in modernized agricultural development. Marine fishery resources as a part of modernized agricultural development, which become a new approach to safeguard China's food security. Under the background of the 'three rural issues', strengthening the rational utilization of marine fishery resources and developing marine fishery production can solve the problem of fishermen's poverty alleviation. At the same time, in

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response to the strategy of 'building a new socialist countryside', the exploitation of marine fishery resources and the secondary and tertiary industries of marine fishery will be integrated developed to promote urbanization and new rural construction. However, resources declined and destruction of the ecological environment in marine fishery has not been fundamentally changed currently. Marine fishery in various regions of China still face many severe challenges such as extensive development mode and serious sea pollution, and the vulnerability in the development of marine fishery has gradually become prominent. The research of vulnerability is one of the core issues of global change and sustainable development research and also serves as an important criterion for measuring the extent of development in a region (Jin and Wang, 2016), and research on vulnerability assessment and sustainable management of ecological environment vulnerability has gradually become a hot global academic field (Kates et al., 2001; Turner II et al., 2003; Xu et al., 2009; Wang et al., 2012; Li et al., 2018). The research was originally proposed from the study of natural disasters in the late 1960s (Timmerman, 1981), and developed in the theory of the rights in food security in the early 1980s (Vogel, 1998) and then permeate various disciplines such as ecosystems, economic systems, sociology, geosciences, and sustainable development (Kasperson and Kasperson, 2001; Chambers, 2006; Yuan et al., 2015). In recent years, international scientific programs such as Man and Biosphere (MAB), International Geosphere-Biosphere Program (IGBP), and International Human Dimensions Programme on Global Environmental Change (IHDP) have been involved, which accelerated the process of research in vulnerability by a lot of scholars (Bohle, 2001; McCarthy et al., 2001; GLP, 2005).

Foreign research on the vulnerability of marine fishery has been transformed from a single disturbance factor to multiple disturbance factors. Himes-Cornell et al. (2016) evaluated the vulnerability of Alaska's fishing community from a socio-ecological perspective; Cinner et al. (2012) evaluated and compared the social ecosystem vulnerability of 12 coral reef fisheries in Kenya through environmental exposure, ecological sensitivity, ecological restoration potential, social sensitivity and social adaptability. And then adopt climate change as the main research background of the micro-level vulnerability of marine fishery gradually; Allison et al. (2009)

built a vulnerability model to evaluate the economics vulnerability of marine fishery in 132 countries when face the climate change impacts; Das et al. (2016) evaluated the vulnerability of inland fisheries to climate change in 13 counties in West Bengal, India; Chen et al. (2014) built a new vulnerability assessment framework to identify and measure the vulnerability drivers of underutilized fishermen under climate change. With the deepening of relevant research, the transition from vulnerability to adaptability of marine fishery has been realized: Johnson and Welch (2016) identified marine species with high, medium and low vulnerability within the Torres Strait under climate change in 2030 through a semi-quantitative framework in order to reduce vulnerability and improve adaptation. Domestic marine fishery researches mainly focus on the sustainable utilization of resources, industrial transformation and marine fishery development assessment under a single system. On the aspect of sustainable utilization of marine fishery resources, Sun et al. (2016) respectively clarified the specific appearance of the sustainable utilization characteristics of marine fishery resources from the perspective of temporal and spatial; Tang et al. (2009) believed that the overall marine fishing industry in China tends to be stable, it is beneficial to promote the sustainable development of marine fishery resources by standardizing relevant systems of capture fishery; Chu (2010a) thought that the precautionary principle should be incorporated into the sustainable utilization of China's marine fishery resources. On the aspect of marine fishery transition, Tong et al. (2017) clarified the structure of China's marine fishery industry, pointed out how did the marine fishing industry and aquaculture turn to the supply-side structure reform after run into bottleneck and proposed corresponding countermeasures; Geng and Tong, (2012) started from the transition of fishermen's research and considered that the transition of marine labor is an important part of the transition of marine fishery; Yang and Su (2010) proposed that the marine fishery industry structure needs to be optimized and transformed to achieve the combination of economic benefits and ecological benefits of marine fishery in order to avert on account of industrial isomorphism that impede the development of marine fishery. And among the researches of marine fishery development assessment under a single system, many scholars (Chang et al., 2010; Chu, 2010b; Xu et al., 2011; Wang and Guo,

2014) mostly concentrated on the quantitative and qualitative research under the marine fishery ecosystem, capturing the problems existing in the resource use efficiency, policy formulation and management of marine fishery on a small scale. Compared with foreign studies, the domestic research about the marine fishery vulnerability seems inadequate and still in its infancy. Ding (2017) only analyzed the degree of vulnerability of marine fishery in the face of climate shocks on the global scale; Chen and Hu (2018) evaluated the vulnerability of China's marine fishery based on the socio-ecological system perspective; and, Li et al. (2019) focused on the vulnerability of marine fishery in the field of industrial ecosystem that analyzes the spatial and temporal evolution and influencing factors of it in China's coastal areas. But, in the assessment of the marine fishery vulnerability, there has not small scale research yet. As an important barrier for the safety of marine ecological environment and a buffer zone against global climate change, Bohai Sea is facing a series of problems such as industrial structure change, ecological environment damage while developing marine fishery economy. During the Two Sessions in 2019, the ministry of ecological environment firstly proposed to 'fight pollution prevention and control', and emphasized the strengthen of comprehensive improvement of Bohai Rim Region. Thus, the marine fishery industry, as a part of depending on its marine industry development and ecological en-

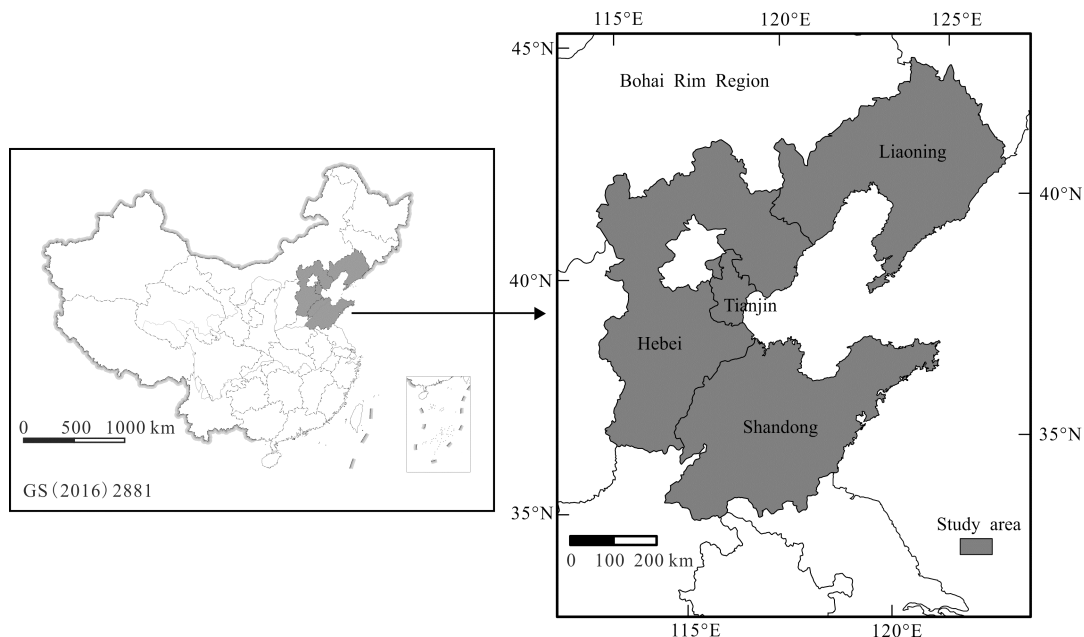
vironment change in Bohai Rim Region, which system vulnerability has gradually turned into the spotlight of experts and scholars close attention.

In view of this, the paper based on the previous research framework of marine fishery industry ecosystem vulnerability, focusing on the small scale area of Bohai Rim Region, and combining with the entropy method and Topsis which deeply reveals and assesses the spatio-temporal evolution characteristics of the marine fishery industry ecosystem vulnerability in Bohai Rim Region on the mesoscale that will conduce to extend the research thread of the China' marine fishery industry ecosystem vulnerability, deepen the research system for the marine fishery sustainable development, respond to the national marine economic development strategy, and solve the practical issues in the process of marine fishery economic development.

## 2 Materials and Methods

### 2.1 Study area

Taking the marine economic zone around the Bohai Rim Region as the object of this study, which is an economic region consisting of the coastal areas surrounding the Bohai Sea (containing part of the Yellow Sea), mainly includes three provinces (Liaoning Province, Shandong Province, Hebei Province) and one city (Tianjin) (Fig. 1). The Bohai Rim Region provides the development



**Fig. 1** Location of study area

foundation of marine fishery with its abundant marine biological resources, tidal-flat resources and epeiric sea resources. In addition, the Bohai Sea, as China's largest inland sea, encompasses two major marine fishery production provinces nationwide, with a sea area of 7.7 million ha and more than 290 species of fish resources. Meanwhile, the tidal-flat area of Bohai Rim Region covers an area of more than 7478.7 km<sup>2</sup>, which is 0.87 times and 3.65 times that of the Yangtze River Delta Region and the Pearl River Delta Region respectively; and epeiric area covers an area of 3.171 million ha, which is 0.68 times that of the Yangtze River Delta Region. Furthermore, by 2015, the Bohai Rim Region achieved a total of 19.67 billion yuan (RMB) on the GDP of marine fishery, while the marine capture production and marine aquaculture production were 3.69 million t and 8.45 million t respectively accounting for 28% and 45.1% of the national total, which make a contribution to the total value of the national marine fishery industry as high as 40%.

## 2.2 Index selection of marine fishery industry ecosystem vulnerability in China

### 2.2.1 Identification on marine fishery industry ecosystem

The proposal of marine fishery industry ecosystem is based on the requirement of marine fishery industry sustainable development, and resolves the contradiction between the development of the marine fishery industry and the environment and resources, which aims to reshape the existing industrial economic mode in the light of material circulation and energy flow patterns of the natural system and obtain the unification of economic benefit and ecological benefit from the efficient utilization of resources, the reduction of the industrial and subsistent wastes emissions. Specifically, the system consists of marine fishery industry subsystem and marine fishery environment subsystem. The marine fishery industry subsystem keeps development and utilization of marine fishery resources as the central task, including marine fishing, marine aquaculture, and upstream and downstream industries that extend from marine fishing and marine aquaculture. The marine fishery environment subsystem is composed of the marine fishery ecological environment and social environment. Thereinto, the ecological environment namely the strengths and weaknesses of marine biological resources themselves

and their habitat, to a certain extent related to the survival, development, reproduction, death, supplementation, action, distribution and resource ups and downs of marine fish. And the social environment like the ethical standards, views and values, education, laws, policies, employment and S&T level formed by people who produce or live on the basis of the marine fishery industry.

### 2.2.2 Definition on vulnerability of marine fishery industry ecosystem

The vulnerability in the development of marine fishery in Bohai Rim Region are gradually exposed, which from the innate instability and sensitivity of the internal structure of this system itself, and also mainly caused by external pressure and interference that causes damage to the system and irreversible changes. The former is structurally vulnerability and the latter is coercive vulnerability. The Bohai Rim Region has faced with the comprehensive problems of sustainable development due to constraints on marine resources, structure, system and market, and overexploitation of marine fishery resources has led to resource depletion, ecological damage and even environmental disasters. For a long time, the singular industrial structure formed by excessive dependence on marine fishery resources, the diversified economic structure still shows immature, and the external conditions for cultivating the competitive advantages of the marine fishery industry are lacking, which resulting in the structural vulnerability of the marine fishery industry ecosystem. Additionally, under the background of economic globalization, technological progress and industrial structure upgrading have bought greater external competitive pressures to the development and utilization of marine fishery, threatening the stability and sustainability of the economy in the Bohai Rim Region, leading to the vulnerability of the marine fishery industry ecosystem eventually (Li, 2019). Therefore, the marine fishery industry ecosystem vulnerability is a coupling value of the sensitivity degree on marine fishery industry itself to multiple internal and external pressure shocks and the resilience degree coped with these disturbance factors, which is used to judge the quality and the speed of the marine fishery economy development among regions.

### 2.2.3 Index system construction

This paper take the sensitivity-response capacity proposed by Gallopín (Gallopín, 2006) as the assessment framework for marine fishery industry ecosystem vul-

nerability. Among them, sensitivity refers to the changes in the system caused by the internal and external environmental disturbances imposed on the marine fishery industry ecosystem; the response capacity refers to the ability of the marine fishery industry ecosystem to restore its original state after resisting the disturbance. Then, the sensitivity index and the response capacity index are respectively assigned to the marine fishery industry subsystem and the marine fishery environment subsystem. In terms of the industry subsystem, the sensitivity of marine fishery industry ecosystem firstly originates from the supply power of its marine fishery resource reserves to its economic development and then comes from the changes in the marine fishery economic development that generated by the marine fishery disaster losses under external stress-induced or the global economic environment disturbance. And the response capacity of this system is manifested as the marine fishery development intensity, the regulatory forces in case of various obstacles to the marine fishery economic development, and scientific research input for boosting high quality development of marine fishery. And according to the environment subsystem, the sensitivity of marine fishery industry ecosystem is derived from the natural resources endowment of the Bohai Rim Region itself, force majeure caused by external natural disasters and even man-made damage. And as for response capacity, firstly, under the condition of ecological environment, it shows the capability of marine environmental governance which is emerged from marine environmental pollution and disasters; secondly, in social environment conditions, on the one hand, it comes from the scientific research ability by scientific research personnel and team in marine risk regulation, assessment and early warning, on the other hand, it stems from the happiness index of the personnel engaged in marine fishery, which is embodied the employment and welfare standards. Therefore, the paper selects 12 first-level indicators and 23 second-level indicators to construct the evaluation index system of marine fishery industry ecosystem vulnerability in Bohai Rim Region (Table 1).

### 2.3 Data resources

This paper selects 2001–2015 as the time series of research. The statistical data were predominantly obtained from China Statistical Yearbook (National Bureau of Statistics, 2002–2016), China Ocean Statistical Year-

book (State Oceanic Administration, 2002–2016), China Fishery Statistical Yearbook (Fisheries and Fisheries Administration Bureau of the Ministry of Agriculture, 2002–2016), China Statistical Yearbook for Regional Economy (National Bureau of Statistics, 2002–2016), and other statistical bulletin from 2001 to 2015, such as ‘Non-shore Sea Area Environmental Quality Bulletin’, ‘China Marine Disaster Bulletin’.

### 2.4 Vulnerability evaluation model of marine fishery industry ecosystem in Bohai Rim Region

According to the concept of marine fishery industry ecosystem vulnerability, the sensitivity-response capacity assessment framework, and with the functional expressions which are used to start from the two components of the framework: the sensitivity and response capacity, the factors that under the force of disturbance. Meanwhile, the effect of the two factors on vulnerability is unequal, so the formula is as follows:

$$V_i = (W_1 \times S_i) / (W_2 \times R_i) \quad (1)$$

where  $V_i$  means the vulnerability index of marine fishery industry ecosystem in Bohai Rim Region;  $S_i$  means the sensitivity index of marine fishery industry ecosystem in Bohai Rim Region;  $R_i$  means the response capacity index of marine fishery industry ecosystem in Bohai Rim Region;  $i$  refers to coastal areas in China;  $W_1$  represents the weight of sensitivity;  $W_2$  represents the weight of response capacity.

### 2.5 Evaluation method

Because of the complex nonlinear relationship between vulnerability influencing factors and vulnerability, however, ‘The technique for order preference by similarity to an ideal solution, TOPSIS’ (Hong et al., 2015; Li et al., 2018) is an effective multi-objective decision method, which is based on the standardization of the original data matrix and then confirm the optimal solution and the worst solution, whereafter according to the euclidean distance between each evaluation index with the optimal solution and the worst solution which used to obtain the degree of similarity between the evaluation object and the optimum value as the basis for the final evaluation results. In addition, combining with the entropy method (Wang et al., 2013), the determined weights were assigned to the sensitivity and response-capacity indicators in order to calculate the final degree

**Table 1** Index system and indicator weights for China marine fishery industry ecosystem vulnerability

	First level index	Second level index	Nature	Weights	
Sensitivity 0.754	Marine fishery industry subsystem	Marine fishery resources	Per capita marine fishing production/t	(+)	0.066
		Marine fishery economic pressure	Marine disaster loss/100 million yuan (RMB)	(+)	0.035
		Marine fishery economic development level	Marine fishery economic production value as a share of GDP/%	(-)	0.068
			Per capita marine fishery GDP/(yuan/person)	(-)	0.032
	Marine fishery environment subsystem	Marine environmental pollution	First and second water quality ratio in coastal/%	(-)	0.099
			Industrial direct discharge into the sea wastewater/t	(+)	0.031
		Marine natural disasters	Storm surge area /10000 ha	(+)	0.025
			Red tide disaster area/km <sup>2</sup>	(+)	0.041
		Marine environmental carrying capacity	Per capita sea area/(ha/person)	(-)	0.046
			Per tidal-flat area/(ha/person)	(-)	0.072
Responsibility 0.246	Marine fishery industry subsystem	Marine fishery development intensity	Per capita coastline length/(km/10000)	(-)	0.049
			Marine aquaculture area/ha	(-)	0.028
		Marine fishery economic regulation ability	Production of marine products/t	(-)	0.008
			Marine fishing vessel year-end possessive quantity/ship	(-)	0.084
	Marine fishery environment subsystem	Marine fishery sci-tech input	Marine fishery industry capital return rate/%	(-)	0.010
			Contribution rate of secondary and tertiary industries in marine fisheries/%	(-)	0.043
		Marine fishery environmental Management capacity	Marine fishery research funding investment / 10000 yuan (RMB)	(-)	0.053
			Marine fishery industry solid waste disposal volume/t	(-)	0.014
		Marine fishery sci-tech level	The proportion of personnel with bachelor Degree or above in scientific and technological activities of aquatic research institutions/%	(-)	0.034
			Fishermen's well-being index	Per capita net income of marine fishery/(yuan/person)	(-)
Marine fishery employment/person	(-)	0.045			
Quantity of medical institutions	(-)	0.058			
Engel coefficient	(+)	0.014			

Notes: 1) The symbol '+' is a positive indicator and the symbol '-' is a negative indicator. 2) The per capita net income of marine fishery and other indicators are the indexes composition that under the social environment level of marine fishery industry ecosystem which in order to clarify the financial contribution of the development of marine fisheries industry to the local people engaged in marine fisheries, and then to reflect the living conditions of fishermen. 3) Some of the data are secondarily transformed by the relevant formula: ① Return on capital of marine fishery industry = annual increase in marine fishery industry/annual output value of marine fishery industry × 100%; ② Contribution rate of secondary and tertiary industries in marine fisheries = (output value of marine fisheries secondary industry + output value of marine fisheries tertiary industry)/total economic output value of marine fishery × 100%; ③ Engel coefficient = total food expenditure/total expenditure of consumption; ④ Disposal of solid waste in marine fishery industry = amount of industrial solid waste treatment × (total value of marine fishery economy/gross national product)

of vulnerability of marine fishery industry ecosystem in Bohai Rim Region from 2001–2015.

### 3 Results Analysis

Based on the average value of the marine fishery industry ecosystem vulnerability index in the Bohai Rim Region from 2001 to 2015. Average (AVG) = 2.53 and standard

deviation (SD) = 1.07, using the mean standard deviation classification statistical method (Qin et al., 2014), taking Table 2 as the marine fishery industrial ecosystem vulnerability assessment standard, and selecting the year of 2001, 2005, 2010 and 2015 as representative nodes by natural fracture method, meanwhile, with the help of ArcGIS10.2 to visualize the spatial evolution trend of the vulnerability of marine fishery industry ecosystem in the Bohai Rim Region.

**Table 2** Criteria for classification of marine fishery industry ecosystem vulnerability

vulnerability index	$0 \leq V < (AVG - SD)$	$(AVG - SD) \leq V < AVG$	$AVG \leq V < (AVG + SD)$	$(AVG + SD) \leq V$
	$0 \leq V < 1.07$	$1.07 \leq V < 1.46$	$1.46 \leq V < 3.59$	$3.59 \leq V$
vulnerability level	Minimum vulnerability	Medium vulnerability	Higher vulnerability	Maximum vulnerability

### 3.1 Temporal evolution characteristic

As shown in Fig. 2, from 2001 to 2015, the vulnerability of the marine fishery industry ecosystem in the Bohai Rim Region showed a volatility diminishing trend in terms of time series, illustrating that the overall development of the marine fishery industry ecosystem in the Bohai Rim Region is favorable while management still needs to be strengthened. In individual years, systemic vulnerability has risen slightly due to sudden high sensitivity factors or lack of timely response capacity. In the aspect of sensitivity, the marine fishery industry ecosystem in the Bohai Rim Region showed significant dynamics in the year of 2007, 2010 and 2012. From the perspective of response capacity, the marine fishery industry ecosystem of Bohai Rim Region presented a rapid development state taking 2008 as the node within the 15 years.

(1) At the beginning of the 21st Century, the development of marine fishery in the Bohai Rim Region mainly relied on the marine fishing industry to increase the marine fishery GDP, however, the excessively single marine fishery industry structure has caused a large number of marine fishery resources to shrink. As of 2003, the marine fishery production of the Bohai Rim marine economic zone was as high as 1.3 million t, which was 1.6 times that of the suitable catchable amount in the Bohai Rim Region. On account of overfishing caused the decline of the marine fishery carrying capacity in the Bohai Rim Region, thus indirectly destroying the nearshore state waters environment. As a result, the sensitivity of the marine fishery industry ecosystem has increased, and in turn, the sustainable development has been seriously threatened. In addition, without the regulation of response capacity which have led to a trend of high vulnerability jointly. However, since the 'Eleventh Five-Year Plan', the government has continuously improved the protection and ecological restoration of marine fishery around the Bohai Rim Region. Carrying on this good momentum, Liaoning Province and Hebei Province successively issued the 'Implementation Opinions on Promoting the Sustainable Development of Marine Fisheries' to guide the devel-

opment of marine fishery industry in this region; as a pilot project for national marine economic development, Shandong Province and Tianjin have clearly proposed to develop a modern marine fishery industry, which is by controlling the intensity of marine fishing, responding promptly to the midsummer moratorium system, carrying out enhancement and releasing activities, artificial reef construction and other comprehensive measures to strengthen the ecological environment restoration and the conservation of marine fishery resources which have promoted the steady development of marine fishery in the Bohai Rim Region. At the same time, the three provinces and one city of this region actively adjusted the functional zoning of offshore waters, continuously expanded the scope of marine aquaculture and implemented high-quality and refined marine aquaculture vigorously, which made marine fishery species are effectively recovered and the yield is increased accordingly. To a great extent, it also can further optimize the marine fishery industry structure, and alleviate the development model of a single marine fishery based on overfishing. Thus it can be seen, the Bohai Rim Region has strengthened the response capacity of industry ecosystem from the development of marine fishery industry and marine fishery ecological environment protection, which has promoted the gradual decline of the marine fishery industry ecosystem vulnerability in the Bohai Rim Region.

(2) Notwithstanding the overall vulnerability of the marine fishery industry ecosystem in the Bohai Rim Region shows gradually declined, there is still a volatility increase in individual years. The reason is that in 2007, the offshore waters around the Bohai Rim Region was affected by the industrial expansion of the nearby provinces, the percentage of industrial pollution exceeding the standard was as high as 91%, bringing about serious water pollution and directly affecting the habitat environment of sea fishes in coastal waters, causing a large number of aquatic organisms unto death, and a sharp decline in the production of marine fishery. These combined status quos make the sensitivity factors of the marine fishery industry ecosystem improve rapidly,

which led to the vulnerability index of marine fishery industry ecosystem rebound eventually. In 2010, due to the disturbance of seawater intrusion, the salinization area near the Bohai Rim Region gradually expanded, which caused damage to the coastal ecosystem to a certain extent, forcing the reduction of marine biodiversity. Meanwhile, the marine ecological monitoring areas in the Bohai Rim Region were mostly in a sub-healthy and unhealthy state, which made the system sensitivity increase suddenly, but the proper response capacity offset the increase of the vulnerability credited by the high sensitivity. During the year of 2012, the Bohai Sea was polluted by high concentration once again, with an area of 53%. Among them, the sea area of the class four water quality standard and inferior to the class four water quality standard are accounted for 1/2 of the polluted sea area. The number of marine fishery professionals in this region has decreased by nearly one million, and also without the sufficient support of marine fisher's labor force, which intensified the sensitivity factors improvement in this industry ecosystem again simultaneously. In the same year, at the beginning of the 'Twelfth Five-Year Plan', the regulation of marine fishery system was still in the running-in phase, which was lack of timely and proper response capacities. Therefore, based on the above two aspects caused the vulnerability risen of the marine fishery industry ecosystem in the Bohai Rim Region.

### 3.2 Spatial evolution characteristic

From 2001 to 2015, the vulnerability of the marine fishery industry ecosystem in the Bohai Rim Region shows a stair-like feature of being high in the east and low in the west (Fig. 3). Specifically, the vulnerability of

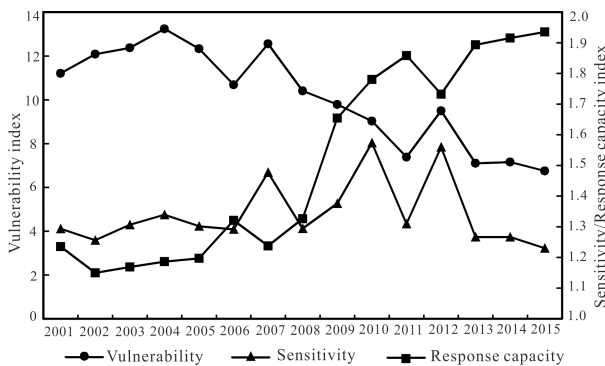


Fig. 2 The trends of vulnerability, sensitivity and response capacity of marine fishery industry ecosystem from 2001 to 2015 in Bohai Rim Region

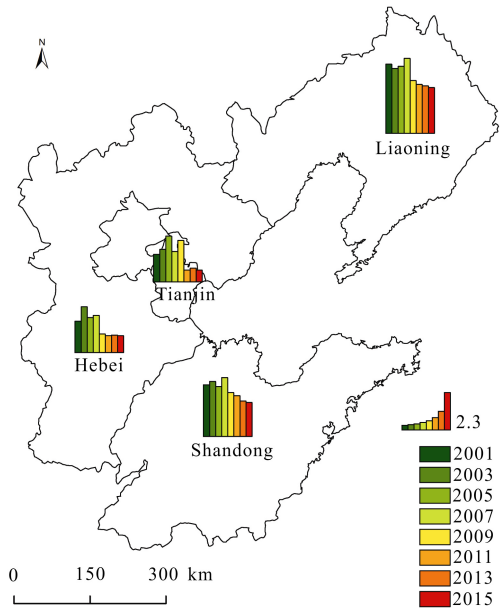


Fig. 3 Vulnerability spatio-temporal of industry ecosystem in Bohai Rim Region from 2001 to 2015

marine fishery industry ecosystem in Liaoning and Shandong provinces are significantly higher than that in Hebei Province and Tianjin. In general, within the past 15 years, the marine fishery industry ecosystem in the Bohai Rim Region was mainly distributed in the maximum and higher vulnerability areas, but the vulnerability of various provinces and city of Bohai Rim Region has shown a downward trend, which elucidates the sustainable development of the marine fishery industry in the Bohai Rim Region is flourishing. With some specific problems though, therefore we should pay much attention on optimizing the marine fishery industry and ecological aspects under the system to reduce the distribution of maximum and higher vulnerability areas.

According to the evolutionary trajectory of the marine fishery industry ecosystem vulnerability level of Bohai Rim Region from 2001 to 2015 which presents in ArcGIS10.2, it is divided into 2 spatial evolution structures: 'decreasing' and 'stable' types (Fig. 4).

(1) Among the type of 'decreasing' vulnerability structure provinces, Liaoning Province is a maximum-higher 'decreasing' vulnerability; Hebei Province and Tianjin are higher-minimum 'decreasing' vulnerability.

As for Liaoning Province, the main reasons for the long-term maximum vulnerability of the marine fishery industry ecosystem are as follows: firstly, the ecological



environment in the offshore waters of Liaoning Province is seriously damaged; secondly, the degree of industrialization of marine fishery in Liaoning Province is low, and also the proportion of industrial structure is not coordinated. The combination of the two aspects make the industry ecosystem vulnerability of marine fishery in Liaoning Province appear to be higher. What's more, as one of the important provinces of the old industrial bases in Northeast China, Liaoning Province will inevitably lead to the excessive release of a large amount of industrial wastes with the advancement of the process of industrialization, the pollutants carry excessive Nitrogen, Phosphorus and other elements greatly affected the water quality in the coastal waters and give rise to eutrophication in the offshore waters. And also seriously damage the ecological environment quality of fishery waters, indirectly lead to the safety problem of marine aquatic products, moreover it imposes restriction on the domestic demand and import and export trade of the marine fishery industry and hinders the development of the marine fishery industry in Liaoning Province. Meanwhile, with the weak investment in S&T, inefficient technology transformation rate and the lack of mechanism guarantees of the development of marine fishery industry in Liaoning Province, resulting in the marine fishery industry structure in Liaoning Province being too single and mainly dominated by the marine fishing industry with a low-tech. In terms of industry, the marine fishery in Liaoning province is concentrated in the production of primary products immoderately, resulting in short industrial chain and low added value, also it has curbed the transformation of marine fishery industry to a certain extent; on the aspect of ecology, excessive marine fishing has caused some threats which included marine fishery biodiversity loss, the collapse of the marine ecological environment. Thus, the marine fishery industry ecosystem vulnerability of Liaoning Province kept a maximum level from 2001 to 2010. However, in recent years, Liaoning Province has issued the 'Implementation Opinions on Promoting the Sustainable and Healthy Development of Marine Fisheries', and clarified the idea of 'expanding modern marine fishery construction as the main task' for the development of marine fishery economy, focusing on adjusting production structure and upgrading the construction of facilities and equipment on marine fishery, intensifying the support of science and technology, protecting fish

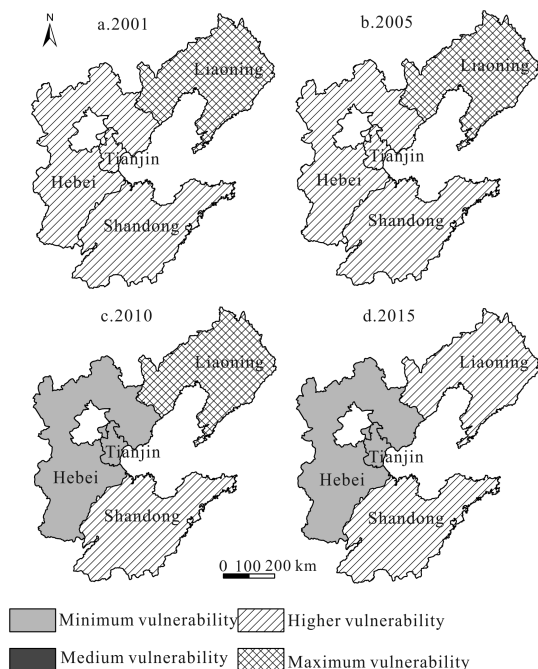
stock and ecological environment, and promoting the sustainable and healthy development of marine fishery in Liaoning Province. By 2012, the marine aquaculture production in Liaoning Province was 2 636 300 t, and the marine fishing was 1.279 million t, the proportion of marine aquaculture and marine fishing was 67.3% : 32.7%, indicating that after the 'Twelfth Five-Year Plan', the marine fishery industry structure in Liaoning province has been further optimized, becoming more reasonable gradually, furthermore, the ecological environment of the coastal waters has been recovering steadily. Then, Liaoning Province has continuously improved the growth mode of marine fishery industry by relying on scientific and technological innovation to strengthen the development of pelagic fishery. At the end of 2015, the pelagic fishing volume was close to 270 000 t, achieving an output value of 2.68 billion yuan (RMB), which promoted the sustainable development of marine fishery industry in Liaoning Province. Ultimately, the vulnerability of the marine fishery industry ecosystem in Liaoning Province presents a good development in a declining trend. Therefore, the development of marine fishery in Liaoning Province should innovate its industrial development mode to promote the construction of marine fishery ecological environment so as to reduce the vulnerability of marine fishery ecosystem.

Hebei Province and Tianjin are located in the center of the Bohai economic circle. The two are geographically adjacent, thus the spatial evolution of the vulnerability of the marine fishery industry ecosystem is generally consistent, showing a transition from higher vulnerability to minimum vulnerability. In the early 21st century, the coastal waters in Hebei Province and Tianjin were seriously polluted which partly led by the discharge of domestic sewage from the rapid economic development, population growth and partly by the industrial sewage from the acceleration of urbanization, harbour construction and oil exploitation of Hebei Province as well as Tianjin. The pollution which made imbalances in the marine ecosystem, frequent red tides, and breeding of diseases, in addition, affected the regeneration of marine fish resources. At the same time, these two areas have not realized the change of the mode of the marine fishery economic growth from extensive form to intensive form, the primary industry still occupied a dominant position in the marine fishery economy, resulting in a decrease of marine fishery di-

versity. Furthermore because of urbanization, and urban land expansion occupied a large number of epeiric sea and tidal-flat area, which made the original narrow breeding space to be compressed again, and also on account of neglecting the role of science and technology in the marine fishery industry, which triggered a rise in marine fishery industry ecosystem vulnerability in Hebei Province and Tianjin. However, with the introduction of the 'Eleventh Five-Year Plan', Hebei Province and Tianjin had insisted on the marine fishery enhancement and releasing, which had achieved positive results. The species of enhancement or transplant of Hebei Province was as high as 15 000 t and the output value was 1.1 billion yuan. As of 2015, Tianjin had invested 124 million yuan in enhancement and releasing of marine fishery, which achieved intensive and efficient development of marine aquaculture and also promoting its improvement of ecological, economic and social benefits. In 2014, driven by the 'Beijing-Tianjin-Hebei Coordinated Development' Strategy, Hebei Province and Tianjin took the opportunity to vigorously transform the development of marine fishery industry, carry out characteristic aquaculture and industrialized aquaculture (Wang et al., 2015), strive to develop recreational fisheries, deepen the development of coastal tourism, and integrate ecological fisheries into the tourism industry to promote coordinated development, improve the restoration and conservation of marine fishery resources, effectively transform the economic growth mode of marine fishery, and gradually perfect the industrial structure, which eventually reduced the vulnerability of the marine fishery industry ecosystem in these regions to a reasonable level. This shows that in the orientation of policy guidelines, the industrial restructuring of marine fishery has accelerated the dispersion of the economic and ecological problems caused by the excessive concentration of marine fishery in a single industry, thus reducing the vulnerability of marine fishery industry ecosystem in this region. From now on, efforts should be directed towards the response of the policy system and optimizing the pattern of the marine fishery industrial growth in the Hebei Province and Tianjin.

(2) Among the type of 'stable' vulnerability structure province, Shandong Province is the higher stable vulnerability. As a large marine fishery production province in the Bohai Rim Region, Shandong Province has been

actively promoting the large-scale, standardization and industrialization of marine fishery for a long time, which has made the added value of marine fishery in Shandong Province at the level of stable. Visible, the development of marine fishery industry in Shandong Province is relatively robust and the marine fishery industry ecosystem vulnerability in the Shandong Province has not been greatly fluctuated on the industry subsystem. But, during the year of 2001–2015, the high vulnerability of marine fishery industry ecosystem in Shandong Province indicates that the factors restricting their development still exist. Wang (2013) pointed out the problems in previous studies that the development of marine fishery in Shandong Province: first, the situation of 'desertification' in offshore waters is still serious; second, the situation of aquatic product quality and safety is not optimistic; third, the construction of marine fishery infrastructure and service system is seriously lagging behind. And in recent years, Shandong Province has consistently adhered to the development goal of 'Giving priority to breeding' marine fishery industry, making the average annual marine aquaculture capacity in Shandong Province as high as 4 273 270 t, ranking first in the country. But excessive marine aquaculture exceeds the capacity of the marine environment, leading to deterioration of marine fish germplasm resources and the aquaculture diseases. Besides, the accumulation of a large number of aquaculture pollutants and the discharge of industrial and domestic sewage have forced the deterioration of marine ecological environment, coastal eutrophication, and frequent disasters such as red tides. In 2009, there were four times of red tide disasters in the coastal waters of Shandong Province, covering an area of 5279 km<sup>2</sup>, which led to the reduction of marine fishery resources and largely affected the sustainable development of marine fishery. Thus, the marine fishery industry ecosystem in Shandong Province has maintained a higher degree of vulnerability ultimately. It indicates that the ecological environment factor is the main reason for the upsurge in vulnerability of the marine fishery industry ecosystem in Shandong Province. Hence, the development of marine fishery industry should be carried out from the ecological environment protection of the sea area to promote the stable and coordinated development of the marine fishery industry in Shandong Province.



**Fig. 4** Vulnerability degree distribution of the marine fishery industry ecosystem of Bohai Rim Region from 2001–2015

#### 4 Conclusions

Based on the above calculation and analysis, the conclusions are as follows:

(1) On the temporal dimension, from 2001 to 2015, the vulnerability of the marine fishery industry ecosystem in the region shows a general trend of decreasing. However, in the year of 2007 and 2012, the systemic vulnerability appears a slight upward stage, while the overall development pattern of marine fishery in the Bohai Rim Region is good. It illustrates that China is gradually attaching importance to the Bohai Rim Region as an important position of China's marine fishery development economic circle and through the development of the marine fishery to drive the steady progress of maritime power strategy in Bohai Rim Region.

(2) In the spatial dimension, the vulnerability of the marine fishery industry ecosystem in the Bohai Rim Region is formed by the east-high and west-low stair-like feature. According to the evolutionary trajectory of the system vulnerability grade, the Bohai Rim Region marine fishery industry ecosystem is divided into 'decreasing' and 'stable' type of vulnerability evolution structures.

(3) In general, from 2001 to 2015, the marine fishery industry ecosystem in the Bohai Rim Region showed a downward trend in vulnerability except for Shandong Province. However, the overall system is still mainly based on the higher vulnerability, which gathered in Liaoning Province and Shandong Province. In recent years, the systemic vulnerability of Hebei Province and Tianjin has been changing from higher to minimum, and the overall situation is better than that of Liaoning and Shandong provinces. Therefore, the development of marine fishery in the Bohai Rim Region needs to be started from the aspects of marine fishery ecological environment, the development mode of marine fishery industry. We continuously intensify the marine environment rectification efforts, strengthen monitoring of pollution sources in the estuaries of major rivers such as the Haihe, Liaohe, Luanhe and Xiaoqinghe rivers, meanwhile, we implement total COD, Nitrogen, and Phosphorus controls in the coastal waters of the Bohai Rim Region, and move and rebuilt severely polluted enterprises in coastal areas to protect water sources; besides, we optimize the marine fishery industry structure, formulate the development plan of marine fishing and aquaculture industry in Bohai Rim Region according to local conditions, and also vigorously develop pelagic fishery by relying on the advanced fishing technology and the equipment investment of pelagic fishery, so as to achieve the oceanization, and deepening of marine fishery economy in Bohai Rim Region; furthermore, we should enhance the training of scientific and technological personnel in marine fishery industry, and develop a talent structure that is led by specialized personnel and improves the quality of grassroot practitioners, which will make the marine fishery in the Bohai Rim Region development toward the characteristics of green, circular and sustainable.

Under the extensive research framework of industry ecosystem, the issue inquires into the vulnerability of marine fishery industry ecosystem, which provides a new research perspective for the sustainable development of marine economy. By constructing a vulnerability assessment system for the marine fishery industry ecosystem in the Bohai Rim Region, the sensitivity and response capacity of marine fishery under the industrial ecosystem are clarified, which is conducive to the sustainable development of marine fishery in the Bohai Rim Region. As the vulnerability of marine fishery in-

dustry ecosystem research has still in its infancy, further screening of relevant indicators is needed. In addition, in order to improve the overall judgment of the sustainable development of marine fishery in the Bohai Rim Region, the early warning analysis of the marine fishery industry ecosystem vulnerability and the adaptation research of the marine fishery industry ecosystem in the Bohai Rim Region will become the emphasis studying direction in the future.

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