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Current situation analysis and development suggestions of the *Apostichopus japonicus* culture industry in Shandong Province

Guo-Dong Wang[1,6], Cai-Yun Li[2], Cheng-Lin Li[3], Ming Hu[4], Tao Xu[5]*, Ke-Feng Xu[3]*

[1] *Marine Science and Engineering College, Qingdao Agricultural University, 266109, Qingdao, Shandong Province, China*

[2] *Jinan Vocational College, 250002, Jinan, Shandong Province, China*

[3] *Marine Science Research Institute of Shandong Province (National Oceanographic Center, Qingdao), 266104, Qingdao, Shandong Province, China*

[4] *Rizhao Fisheries Technology Extension Center, 276826, Rizhao, Shandong Province, China*

[5] *General Station of Fishery Development and Resource Conservation in Shandong Province, 250013, Jinan, Shandong Province, China*

[6] *Marine College, Shandong University, 264209, Weihai, Shandong Province, China*

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Abstract

In the 1980s, Shandong Province took the lead in establishing breakthrough industrialized seedling raising and breeding technologies for *Apostichopus japonicus* and successfully led the 'fifth wave of mariculture' in China. In 2008, the experiment of 'raising sea cucumber from north to south' proved successful, and sea cucumber culture gradually radiated and extended to Fujian, Jiangsu, Guangdong, and Zhejiang Provinces in southern China. The total output of sea cucumber culture in Shandong Province accounts for more than 70% of the market in China, and the sea cucumber industry is now a pillar of the fishery economy in Shandong Province. This paper systematically introduces the development status of the sea cucumber breeding industry in Shandong Province in recent ten years, summarizes the current problems and challenges, and puts forwards development suggestions; this guidance has significance for the healthy and sustainable development of the sea cucumber breeding industry in both Shandong Province and the whole country.

* Corresponding author. Tao Xu, E-mail: xutao_78@126.com ; Ke-Feng Xu, E-mail: xukefenghyzx@sd.cn

Introduction

Apostichopus japonicus is a sea cucumber of the echinoderms that is naturally distributed in the north of the Western Pacific, including the coasts of Russia's Far East, Japan, and South Korea, China's Yellow Sea, and the Bohai Sea (Sloan, 1984; Liao, 1997; Wang et al., 2015). Because sea cucumber is rich in essential nutrients and bioactive substances such as saponins, acidic mucopolysaccharides and lectins, it ranks first among the 'Eight Treasures of Marine Products' (Sun et al., 2010; Moon et al., 1999; Fan, 2001). In China, sea cucumber is a pillar species of the mariculture economy. The sea cucumber industry is mainly concentrated in the coastal areas around Liaodong and Shandong Peninsula. In the 1980s, Shandong Province took the lead in establishing the breakthrough industrialized seedling breeding technology of sea cucumber, and successfully led China's "fifth wave of mariculture". There are also a few other sea cucumber varieties with low economic value in southern China. Due to market demand and its considerable economic benefits, the sea cucumber industry is experiencing an upsurge as it moves to the eastern and southern coastal provinces of China (Jiang et al., 2017).

Shandong is an important source of sea cucumber and the most significant sea cucumber breeding province in China. The breeding grounds are mainly distributed in coastal areas such as Weihai, Yantai, Qingdao, and Dongying cities (Li et al., 2010; Li et al., 2019; Li et al., 2017; Qiao et al., 2005; Tang et al., 2014). Sea cucumber aquaculture technology has been developing rapidly in China since the 1990s. A series of effective aquaculture technologies and models based on sea cucumber biology have been constructed, such as bottom culture, pond culture, industrial culture, and cage culture methods (Zhang et al., 2015). In order to build 'The Strong Province in Marine Science and Technology', Shandong has formed a relatively perfect whole industry supply chain from seedling raising, breeding, processing, and market circulating, which has effectively promoted the development of the sea cucumber industry in the province and even throughout the whole country (Chang et al., 2006; Sui et al., 2004; Zhang et al., 2004; Yuan et al., 2008). However, bottlenecks still restrict the development of the sea cucumber industry in Shandong Province, which faces many challenges for improving quality, efficiency and green development (Chang et al., 2004; Jiang et al., 2014; Wang et al., 2015; Yang et al., 2015; Qu et al., 2016; Wang et al., 2017).

This paper systematically introduces the development of the sea cucumber breeding industry in Shandong Province and summarizes the problems and countermeasures in the sea cucumber industry; this information provides significant guidance for the high-quality and sustainable development of the sea cucumber industry.

1. Industry Overview

1.1 Breeding scale

From 2011 to 2020, the breeding area of sea cucumber increased from about 510 km^2 to 800 km^2 in Shandong Province, an increase of 55.2% (**Figure 1)**. From 2011 to 2013, it showed an expansion trend; from 2014 to 2016, it showed a contraction trend; and from 2017 to 2020, it showed a stable trend. In 2013 and 2018, the breeding area reached historical highs of 887 km^2 and 881 km^2, respectively. The breeding area of sea cucumber in Shandong Province ranks second only to Liaoning Province in China (Li et al., 2019; Li et al., 2017).

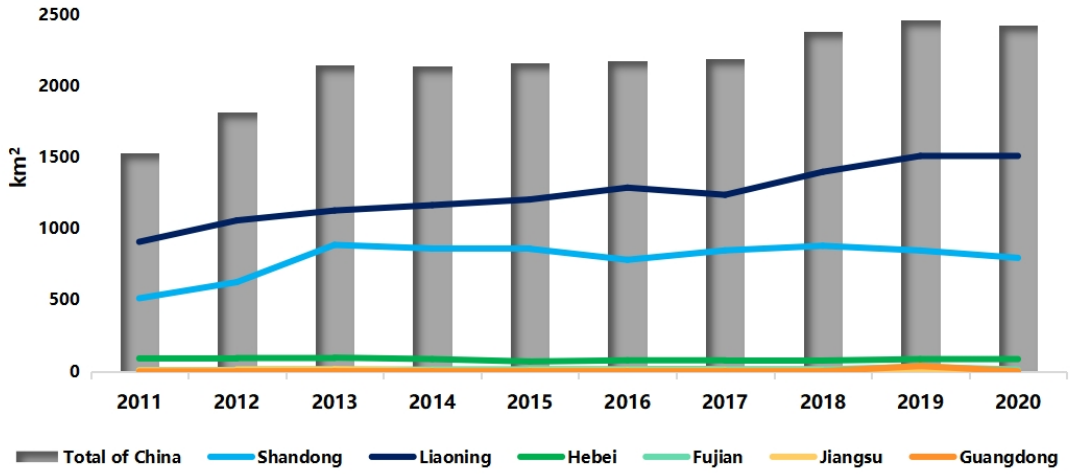

Figure 1 Breeding area of sea cucumber in major provinces in China in recent 10 years (km^2).

Table 1 Proportion of sea cucumber culture scale in major provinces in China in recent 10 years (%)

Provinces	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Shandong	33.43	34.54	41.3	40.26	39.73	35.92	38.75	37	34.37	32.83
Liaoning	59.18	58.36	52.5	54.44	55.68	59.09	56.5	58.76	61.21	62.52
Hebei	6.01	5.25	4.55	4.1	3.27	3.63	3.52	3.23	3.45	3.91
Fujian	0.71	0.88	0.68	0.75	0.8	0.85	0.79	0.67	0.61	0.62
Jiangsu	0.58	0.83	0.82	0.31	0.37	0.35	0.29	0.21	0.2	0.04
Guangdong	0.079	0.16	0.13	0.13	0.13	0.13	0.14	0.13	0.12	0.12

1.2 Breeding yield

From 2011 to 2020, the aquaculture output of sea cucumber increased from about 71 000 tons to 99 000 tons in Shandong Province, an increase of 39.3% (**Figure 2)**. From 2011 to 2015, the aquaculture output increased year by year, exceeding 100 000 tons in 2015. From 2016 to 2020, the annual output decreased slightly, but the overall output remained stable. In 2020, the output of sea cucumber in Shandong Province was about 99 000 tons, accounting for 50.31% of the total output in China, which was 43 000 tons higher than that in Liaoning Province (**Table 2)**.

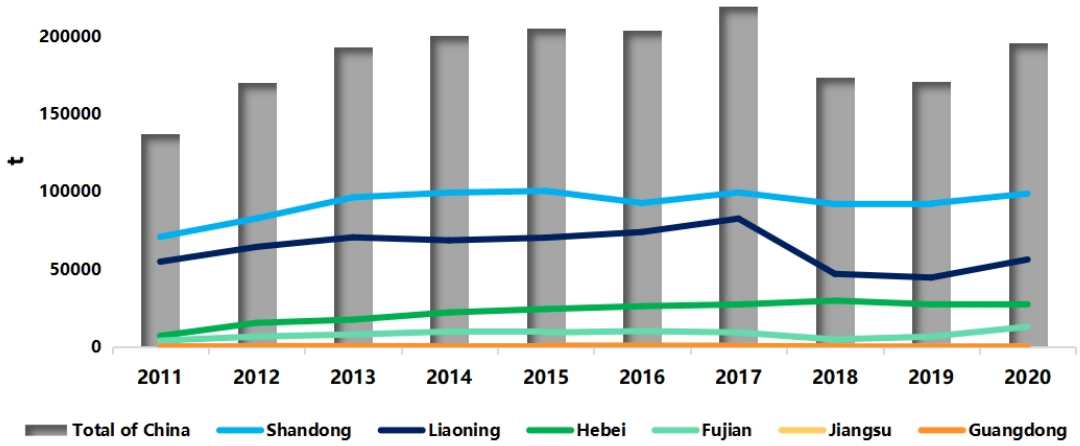

Figure 2 Breeding yield of sea cucumber in major provinces in China in recent 10 years (t)

Table 2 Proportion of sea cucumber output in major provinces in China in recent 10 years (%)

Provinces	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Shandong	51.55	48.53	49.83	49.54	48.91	45.43	45.31	52.90	53.92	50.31
Liaoning	39.89	37.76	36.49	34.21	34.24	36.27	37.65	27.01	26.04	28.68
Hebei	5.14	9.05	9.06	11.06	11.85	12.83	12.44	17.11	15.98	14.28
Fujian	2.92	3.89	4.12	4.89	4.48	4.98	4.21	2.73	3.85	6.60
Jiangsu	0.13	0.14	0.12	0.12	0.12	0.11	0.23	0.07	0.07	0.02
Guangdong	0.18	0.31	0.24	0.14	0.38	0.35	0.16	0.08	0.08	0.04

1.3 Seedling yield

From 2011 to 2013, the seedling yield of sea cucumber in Shandong Province increased rapidly, with a year-on-year growth rate of more than 40% (**Figure 3)**. In 2013, the seedling yield was 44.36 billion, surpassing Liaoning Province for the first time. From 2013 to 2016, the annual seedling output accounted for more than 60% of the national total output and nearly 70% in 2015, reaching the highest output in history (**Table 3)**. In 2020, the seedling output of sea cucumber in Shandong Province was 33.29 billion, accounting for 60.5% of the country's total output.

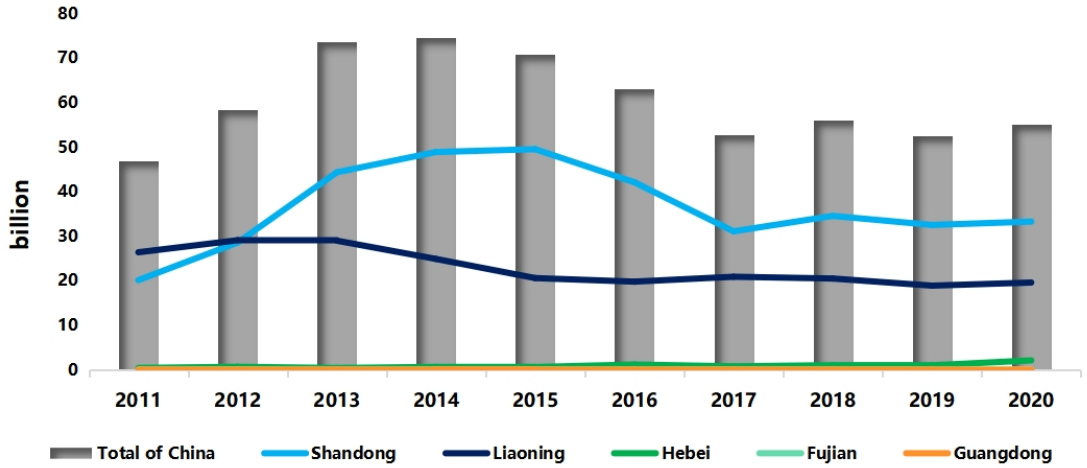

Figure 3 Seedling yield of sea cucumber in major provinces in China in recent 10 years (billion).

Table 3 Proportion of sea cucumber seedling in major provinces in China in recent 10 years (%)

Provinces	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Shandong	42.89	48.96	60.11	65.6	69.99	66.72	58.89	61.52	61.97	60.46
Liaoning	56.19	49.85	39.3	33.4	29.1	31.37	39.58	36.48	36.00	35.60
Hebei	0.90	1.17	0.56	0.89	0.88	1.86	1.48	1.85	1.93	3.84
Fujian	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.04	-	-
Guangdong	-	-	-	0.09	0	0.01	0	0.02	0.01	0.01

1.4 Typical model for seedling raising

Industrialized seedling raising model: Precise breeding, the introduction of high-quality parents, optimization of large-scale seedling cultivation technology in winter, and improvement of mechanized operation of production processes such as feeding and pond

pouring. For seedling sales, the trial breeding + pilot test + promotion + radiation method is adopted to demonstrate and promote sea cucumber seedlings.

Pond ecological circular culture model: Integration and innovation of the stocking specifications, density, timing, and breeding technology of sea cucumber and shrimp seedlings, the establishment of a new relay circular breeding model of sea cucumber and shrimp, reduction of the risk of loss caused by natural factors to the breeding production of a single variety, and improvement of the utilization rate of breeding ponds.

Pond multi-trophic level and high-efficiency breeding model: Introduction of sea cucumber and prawn into the same aquaculture pond to form the mutual utilization and promotion of multi-trophic levels among varieties. The annual average shrimp yield can reach 15.6 g/m^2, the average specification is 11.8 g/ind, and the efficiency benefit is about 2.18 yuan/m^2. This breeding model has been extended to a scale of 15 km^2 in Shandong Province.

Coastal stock enhancement and conservation model: Modern marine ranching should be given high priority for marine fishery health in coastal areas. Chinese marine ranching is vigorously developing, 64 national marine ranching demonstration areas have been completed (Yang et al., 2018). The coastal stock enhancement and conservation of sea cucumber mainly rely on marine ranching. Placement of reef body in the coastal area, with the seedling specification of sea cucumber of be 50 ind/kg. Stocking large specification seedlings can shorten the breeding cycle by 5-10 ind/kg. They were then releasing seedlings in spring and harvesting in autumn, or releasing seedlings in autumn and harvesting in the following spring.

The whole industry chain development model: Development of seedling raising, breeding, processing, marketing, cultural communication, and other industries in a chain, the connection of the primary, secondary and tertiary industries, and formation of an integrated management pattern of fishery, industry, and trade. The sales of sea cucumber deep-processing products, especially active polypeptide series functional foods, increased steadily.

1.5 Economic benefits

Sea cucumber culture. The input of pond culture is 7.5-12.0 yuan/m^2, the output value is 12.0-22.5yuan/m^2, and the profit is about 4.5-10.5 yuan/m^2. According to the breeding output of 225.0-600.0 g/m^2, the cost is 20-35 yuan/kg, and the profit is 15-20 yuan/kg.

Sea cucumber coastal bottom sowing. The cost mainly consists of seedling, ship fuel, maintenance, harvest, labor cost, remote monitoring facilities, etc. The seedlings sown to the coastal bottom can reproduce naturally in the following years. Therefore, the price is also related to the seedling specification. The estimated cost of coastal bottom sowing is 25-60 yuan/kg, and the profit is 60-70 yuan/kg.

Sea cucumber processing. With different processing methods, the cost and profit fluctuate considerably. 3-5 kg fresh sea cucumber can be made into 1 kg instant sea cucumber, the price is 400-500 yuan/kg, and the profit is 40-140 yuan/kg; 25-30 kg fresh sea cucumber can be made into 1 kg dry sea cucumber, the cost is 3000-6000 yuan/kg, and the profit is 1000-1400 yuan/kg. The profit of rough processing products is the same as that of breeding, and the profit of dry processing sea cucumber can reach 20-40 times that of breeding.

1.6 Brand building

Regional public brand: In 2013, Shandong Provincial Fisheries Association and other departments began to strengthen efforts to build a regional brand of 'Jiaodong Sea cucumber,' and the leading enterprises in the main producing cities of sea cucumber responded positively. 'Weihai Sea cucumber,' 'Yellow River Estuary Sea cucumber' and other regional characteristic brands were launched one after another. In evaluating the regional public brand value of China's agricultural products in 2015, 'Weihai Sea cucumber' became the seafood brand with the highest value, with a brand valuation of RMB 5.137 billion. In December 2016, 'Jiaodong Sea cucumber' and 'Weihai Sea cucumber' were

successfully selected as the most influential regional public brands of aquatic products in China.

Corporate brand: In recent years, enterprises such as Homey Aquatic Development Co., Ltd. and Yantai Huakang Marine Food Co., Ltd. in Shandong Province have continuously improved the brand popularity of sea cucumber. The brands of 'Laoyinjia,' 'Shuangju Sea cucumber,' 'Shangbaxian Sea cucumber,' 'Shenlong Island Sea cucumber,' and 'Jinluyuan Sea cucumber' are constantly trying the national market.

2. Current problems

The risk of environmental factors has increased. Practitioners generally believe that high temperatures in summer are the primary risk factor affecting the sea cucumber breeding industry. In 2013, 2016, and 2018, extremely high temperatures seriously impacted sea cucumber culture. Due to the influence of global warming, extremely high-temperature weather in summer may occur frequently. Under the superposition of extreme weather, such as concentrated heavy rainfall and ice cover, large green algae, such as *Enteromorpha prolifera,* and harmful algal blooms, the continuous direct and secondary impact rate on the sea cucumber aquaculture industry will continue to increase. The existing sea cucumber technology, especially earth ponds culture, cannot perfectly cope with extreme weather. (Wang et al., 2004; Du et al., 2005; Yu et al., 2007; Jiang et al., 2004).

Seedlings with excellent characteristics are urgently needed. Some seedling enterprises adopt the method of breeding sea cucumbers for generations. The seedling characteristics degenerate clearly, and problems such as a low survival rate, poor stress resistance, and slow growth gradually appear. The technical system of 'improved variety + improved method' is not perfect. There are great limitations in the industrialization and promotion of new varieties of sea cucumber with the advantages of fast growth and strong stress resistance. The collection, preservation, and evaluation technology of germplasm resources are lagging, and sea cucumber enterprises integrating 'breeding, propagation and promotion' fail to be effectively cultivated (Zhu et al., 2012).

Industrial management must be caught up. Aquaculture employees are often older and unaccustomed to using new technologies and cannot deal with natural disasters such as high-temperature summers, rainstorms, and low salt levels. There are imitation phenomena in reef layout, pond cleaning and water quality control issues linked to aquaculture production and management, and regional production characteristics. The entry threshold of the sea cucumber aquaculture industry is low. Policy insurance for sea cucumber aquaculture has not been carried out. Some units leasing collective waters for sea cucumber aquaculture have not applied for aquaculture licenses, and insufficient daily supervision exists, alongside other problems.

3. Development suggestions

Promote the standardized development of the seed industry. Focus on the development of the whole industrial chain of the seed industry of sea cucumber, support the marine fishery biological germplasm resource bank and the original (good) seed farm of sea cucumber at the provincial and ministerial levels to carry out the collection, preservation, identification, evaluation, development, utilization, introduction and exchange of excellent germplasm resources, accelerate the creation of fast-growing and stress-resistant new varieties, build an integrated seed industry enterprise of breeding, propagation, and promotion, and continuously expand the coverage of improved varieties.

Promote green and healthy breeding. In combination with the establishment of healthy national aquaculture and ecological aquaculture demonstration areas, several green health demonstration projects of sea cucumber will be built to integrate scientific and technological innovation resources and innovation achievements systematically. Support the 'Five actions' of green and healthy aquaculture, accelerate the demonstration and promotion of new varieties, new technologies, and new models of the sea cucumber industry, and give play to the rally and driving role of 'improved varieties + improved

methods. Further, optimize industrialized seedling raising model, pond ecological circular aquaculture model, pond multi-trophic level and high-efficiency breeding model, coastal stock enhancement and conservation model, and so on.

Strengthen the support of scientific and technological innovation. Give play to the innovative advantages of colleges and universities involved in fisheries, strengthen the supporting role of the innovation team of modern agricultural, industrial technology systems, systematically carry out significant applied technology research in the fields of breakthrough new varieties, seedling breeding technology, high-temperature summer technology, and green breeding models, and breakthrough several "neck" technologies. Establish a standard innovation platform and a standardized demonstration and promotion platform for sea cucumber breeding in crucial breeding areas and key enterprises (Su et al., 2014; Liu et al., 2013).

Sea cucumber breeding insurance should be developed. Establish and improve the risk guarantee mechanism for sea cucumber breeding, take 'protecting major disasters and costs' as the goal, gradually implement the mutual policy insurance for sea cucumber breeding throughout the whole province, constantly expand the insurance coverage and insurance depth of losses caused by natural disasters such as high temperature, freezing injury, red tide, storm, and rainstorm, and expand the social and insurance coverage. Attract sea cucumber breeding units to join mutual fishery protection.

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