Survey report of coastal areas suitable for operation of IMTA and economic analysis of benefits from replication of IMTA across Shandong Province, PR China

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Contents

1. Background

1.1 Summary of the adjacent oceanic condition of Shandong Province

Shandong Province is close to the Bohai Sea and the Yellow Sea with abundant coastal and offshore resources. The coastline of the peninsula is 3345km, and the intertidal zone is about 4394.5km^2. There are 3 islands above 500m^2, and the intertidal zone is about 219.951km^2. The adjacent sea area of the peninsula is about 3.55×10^4km. With an advantageous geographical position, Shandong Peninsula is an important part of the Western Belt of the Asia-Pacific Economic Circle. It faces the Liaodong Island and the Korean Peninsula across the sea. Since the confirmation of the "Oceanic Shandong" major policy since the 1990s, the marine economy of Shandong Province has developed rapidly. In 2010, the province's marine economic output exceeded 700 billion yuan, ranking second in domestically. The marine industry covers a wide range of industries including marine fisheries, marine transportation, coastal tourism, offshore oil industry.

The coastline of Shandong Province is bordered by Hebei Province in the mouth of the Dakou River, along the Yellow River Delta and Laizhou Bay to the east, and to the west ends at the Xiuzhen river estuary in Jiangsu Province. The administration area is divided into Binzhou, Dongying, Weifang, Yantai, Weihai, Qingdao and Rizhao. Among them, the coastline of Weihai City has the longest coastline about 978km long, accounting for about 1/3 of the total length.

According to the results of the “908 Special Project” Shandong Coastal Rocky Shoreline Survey, the length of the artificial coastline Shandong Province accounts for 38% of the total length of the provincial coastline (Fig. 1). Among them 27% of the coastline is made up of bedrock snorkeling; about 23% is the sandy shoreline; the silt and muddy shoreline only accounts for 12% of the total length of the province's coastline. In addition, there are some river port lines, which are not counted due to their short length.

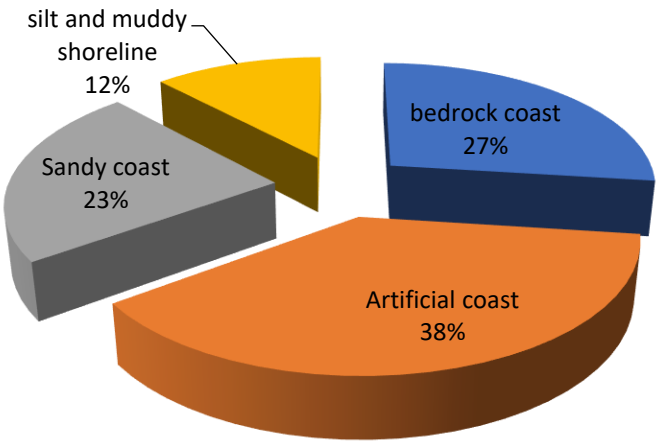

Fig. 1 length ratio of each type of coastline in Shandong province

1.2 Climate

The general climate of Shandong Province is controlled by the East Asian monsoon system, with the characteristics of "hot and rainy summer, cold and dry winter". It also has the characteristics of frequent mid-latitude weather system activities and various types of disasters. It also has a microclimate peculiar to the boundary between two different physical properties (land/sea). In summary, the salient features are: rich climatic resources; seasonal changes are obvious; severe weather events are frequent; climate difference between southeast and northwest part of the peninsula is obvious; climate has transitional characteristics; wind direction has daily changes, namely sea and land breeze, wind speed has mutation; there are more sea fog along the southeast coast.

The total annual solar radiation in Shandong Province is 494042-544284Jcm^2, the radiation is richer in the west of Yantai city. The annual sunshine hours in the coastal area is 2438-2827h.

The annual average temperature of Shandong Province has a spatial distribution, which decreases from inland to coastal. The annual average temperature in the coastal area is within 11.1-12.6℃, which is 1-3℃ lower than the inland. The coldest month in the coastal areas occurred in January, with an average temperature of -2.8 to -4.3 ℃ in the Bohai Sea and -1.0 to -3.2 ℃ in the Yellow Sea.

The annual precipitation in Shandong Province is decreasing from the southeast coast to the northwest. The average annual precipitation in the coastal area of the province is 580-916mm. The average annual precipitation is greater than or equal to 0.1mm days, the Bohai area is 65-80d, and the Yellow Sea area is 80-90d. The annual average precipitation days of 10mm are 15-18d in the Bohai area and 18-25d in the Yellow Sea area; the average annual

precipitation days of 25mm or more is about 6-7d in the Bohai area and 8-11d in the Yellow Sea.

The coastal area of Shandong Province is one of the regions with the richest wind energy in the country. The wind energy resources in the northeastern part of Weishan Mountain are the most abundant, followed by the sea area near Long Island and the eastern part of the southern Yellow Sea.

1.3 Adjacent Sea area

The "Declaration of the People's Republic of China's Territorial Sea Baseline" (May 15, 1996) stipulates that Shandong Province has a total 8 territorial sea base points containing: Shandong High Angle (1) (37°24.0'N, 122 ° 42.3'E), Shandong High Angle (2) (37°23.7'N, 12242.3E), Moye Iland (1) (36°57.8'N, 122°34.2'), Moye Iland (2) (36°55.1'N, 122°32.7'E) , Moye Iland (3) (36°53.7′N, 122°31.1′E), Sushan Island (36°4.8′N, 122°15.8′E), Chaolian Island (35°53.6'N, 120° 53.1'E), Dashan Island (35°59.2′N, 119°54.2′E). The connection between each points is the baseline of the territorial sea in Shandong. The inner sea of Shandong Province is located within 12 nautical miles in the south of the Bohai Sea and the baseline seaward side of the Yellow Sea territorial sea, with a total area of about 3.55×10^4 km^2. The total area of the adjacent sea area of Shandong Province is about 15.96×10^4km^2.

The total area in the continental coast of Shandong Province is 31105.16km^2. Among them, the sea area of 0--30m water depth is 61140km^2, accounting for 38.31% of the total area; the sea area of 0--50m depth is 97499km^2, accounting for 61.11% of the total area. In order to develop and utilize marine resources more scientifically and rationally, and make full use of the space in the vertical depth of the ocean, statistics are carried out on sea areas of different depths in Shandong Province, as shown in Table 1.

Table 1 Statistical table of sea areas at different depths in Shandong Province (km^2)

Depth	Area (km^2)	Proportion of sea area (%)
Coastline to 0m isobath	4395	2.75
0 to 5 m depth	3565	2.23
5-10 m depth	4553	2.85
10-20 m depth	19660	12.32
20-30 m depth	28967	18.15
30-40 m depth	19634	12.31
40-50 m depth	16725	10.48
50m isobath to depth	62058	38.89

Total	159557	100.00

1.4 Sea Jurisdiction

The sea area under the jurisdiction of Shandong Province is from the coastline to the outer boundary of the territorial sea. The total area of the coastal waters is 3.55×10^4 km^2. The area near the coastal area of Bohai Sea is 1.19×10^4 km^2, and the area of the Yellow Sea is about 2.36×10^4 km^2. The largest coastal area in Shandong Province is Yantai City, with a sea area of 11512.28km^2, accounting for 32.43% of the total sea area of the province; the smallest sea area is Binzhou and Weifang, with a sea area of 1134.63km^2 and 1417.24km^2 respectively. The total area of the sea is 3.76% and 3.99% (Table 2).

Table 2 Area of sea areas under the jurisdiction of Shandong coastal cities (km^2)

City	Area (km^2)	Area percentage (%)
Qingdao	8445.34	23.79
Dongying	4063.08	11.45
Yantai	11512.28	32.43
Weifang	1417.24	3.99
Weihai	4868.71	13.72
Rizhao	3857.88	10.87
Binzhou	1334.63	3.76
Shandong (Total)	35499.16	100.00

1.5 Sea usage type and corresponding area in Shandong Province

The use of sea areas in Shandong Province was classified according to the Classification System of Sea Areas (State Oceanic Administration, 2008). By the end of 2007, the sea of fishery in Shandong Province accounted for the largest proportion, accounting for 94.10% of the total sea area. The mineral sea area accounted for 1.35%, and about 2.19% used for land-building project. Subsequently, the amount of transportation is 1.12%, 0.59% for special use, 0.37% for seabed projects, 0.20% for tourism and entertainment, 0.05% for sewage dumping, and 0.03% for other seas. The sea for fishery is used in the development and utilization of fishery resources and for marine fishery which includes fishing infrastructure (fishing port and fishing boat repair), pond culture, facility farming, and bottom-casting seas.

2. Marine aquaculture overview of Shandong Province

(1) Aquatic production in Shandong

In 2016, the total output of aquatic products in Shandong Province reached 9.502 million tons, accounting for 13.8% of the total national aquatic products. Among them, 7.95 million tons of seawater products and 1.552 million tons of freshwater products accounted for 83.7% and 16.3% of the total aquatic products in the province. Among seawater products, 2.292 million tons of offshore fishing, 5.128 million tons of marine aquaculture, and 503,000 tons of offshore fisheries, marine aquaculture accounted for 54% of the province's total aquatic product production.

(2) Areas of different aquaculture in Shandong

Table 3 Areas of different aquaculture in Shandong

Cities	Pond(ha^2)	Cage(m^3)	Long-line (ha^2)	Seabed(ha^2)	Indoor(m^3)
Shandong	104306	3075430	192823	217782	8903029
Qingdao	5636	872548	2507	15423	1478372
Dongying	31667	0	666	73501	67000
Yantai	10497	1633450	97163	55892	3185307
Weifang	6133	0	19640	33602	900000
Weihai	11752	441740	37761	23641	1033500
Rizhao	1502	127620	35086	2790	2202850
Binzhou	37119	0	0	12933	36000

3. Marine development function zone of Shandong Provence

According to the layout of the "National Marine Functional Spatial Planning", on the basis of the "Shandong Province Marine Functional Spatial Planning", the province's marine land space is divided into 29 functional areas, including 8 optimized development areas and 3 key development areas. 18 restricted development areas, as well as point-prohibited development areas. The "Plan" proposes that by 2020, it will basically form a clear spatial balance of the marine main body, a harmonious and balanced coastal population, economic and resource environment, and a coordinated and sustainable development of the marine and land.

According to the “Plan”, Shandong has divided 8 optimized development areas, namely Shouguang City, Longkou City, Yantai City, Jimo City, Qingdao City, Huangdao District of Qingdao, Donggang District of Rizhao City and Laoshan District of Rizhao City. The total sea

area is 16050.58 square kilometers, accounting for 33.93% of the total area of the province's managed waters.

The province has set three key development areas, namely Hanting District of Weifang City, Muping District of Yantai City and Wendeng District of Weihai City. The total sea area is 2995.30 square kilometers, accounting for 6.33% of the total managed area of the province.

The province has a total of 18 restricted development areas, namely Wudi County, Binzhou City Zhanhua District, Dongying City Hekou District, Lijin County, Kenli District, Dongying City Dongying District, Guangrao County, Changyi City, Laizhou City, Zhaoyuan City, Changdao County, Penglai City, Weihai City, Huancui City, Rongcheng City, Rushan City, Haiyang City, Laiyang City and Qingdao Laoshan District, the total area of 27,453 square kilometers, accounting for 58.04% of the province's total managed area. Among them, the total area of the six marine fishery protection zones is 10092 square kilometers; the total area of the 12 key marine ecological functional zones is 17,361 square kilometers.

A total of 19 prohibited zones are confirmed in the province's sea area, including 4 national nature reserves and 7 provincial nature reserves, and 8 territorial sea-point islands.

Table 3 Marine development function zone of Shandong

NO.	Function			City	District	Area percentage
	First level	Second level	Third level			
1	optimization			Weifang	Shouguang	33.93%
2				Yantai	Longkou	
3					Urban area	
4				Qingdao	Jimo	
5					Urban area	
6					Huangdao	
7				Rizhao	Donggang	
8					Lanshan	
9	emphasis			Weifang	Hanting	6.33%
10				Yantai	Muping	
11				Weihai	Wendeng	
12		Marine fishery protection zone		Binzhou	Zhanhua	58.04%
13				Dongying	Hekou	
14				Weifang	Changyi	
15				Yantai	Laizhou	
16				Weihai	Rushan	

17				Yantai	Haiyang	

4. Potential suitable area for aquaculture in Shandong Province

4.1 Potential of marine aquaculture development

(1) Pond Culture

According to statistics, the total area suitable for development of pond culture of Shandong Province is about $3.4\times10^5hm^2$. At present, there are about $1\times10^5hm^2$ has been developed, and $2.3\times10^5hm^2$ is still undeveloped. The undeveloped area is mainly located in the shoreline between Binzhou and Weifang. It is mainly made up of saline-alkali land and wasteland. About $2\times10^5hm^2$ can be developed for sea and underground brackish water pond culture. Furthermore, with the improvement of the salt industrial technology, the proportion of the crystallization pond to the total area of the salt pool is 5%-30%; in addition to the crystallization pond, other ponds can carry out aquaculture, and the Yantian area can be developed to coexist with the culture and salt dual industry.

(2) Bottom Culture

According to statistics, Shandong Province has developed an area of $1.03\times10^5hm^2$ for bottom culture in the inter-tidal zone, and there are still undeveloped tidal flats of 2.4×10^4hm2 mainly located in Binzhou to Weifang section, which can be developed for bottom aquaculture.

The area of the 0-30m isobath in Shandong Province is about $3.2\times10^6hm^2$, among which about $9\times10^5hm^2$ is suitable for the development of the bottom aquaculture. The current bottom culture has been developed mostly within 0-20m water depth ($15\times10^4hm^2$). The sea area beyond 20m is basically undeveloped. It is suitable for the development of sea cucumbers, sea urchins, scallops, crustaceans, etc. And also can be applied for the breeding of carp, big squid and some settlement economy fish.

There are 320 islands with a total area of $500m^2$ or more and a large number of island reefs in Shandong Province. The seabed environment is excellent, suitable for the proliferation of rare seafood and economic seaweed. It is a potential area for aquaculture development.

(3) Shallow Sea aquaculture (long line, cage)

According to statistics, the area of the 5-40m isobath waters in the province can be about $5.3\times10^5hm^2$ for long line and cage culture; there are about $7\times10^4hm^2$ has been developed, mostly within the 5-20m isobath, and there are still $4.6\times10^5hm^2$ sea areas remained undeveloped.

At present, the areas where squatting and cage culture can be carried out in the bays and shallow waters of Shandong Province have been basically developed, but in some areas, the water density is polluted due to excessive culture density, which affects the benefits. IMTA culture should be actively developed, and the cultured sea area should be gradually transferred to the sea areas beyond the deep water 20-30m or even 50m.

(4) Indoor aquaculture

In addition to the cities of Binzhou and Dongying in Shandong Province, the areas where other groundwater is used for indoor aquaculture have been basically developed. Binzhou and Dongying can moderately develop groundwater indoor aquaculture, but the scale of development need to be controlled. The area of land-based aquaculture using groundwater in other cities should limited to a certain scale. Latest methods and technologies should be adopted to save water and reduce emissions, and the production per unit area should be increased. At the same time, natural seawater indoor aquaculture should be vigorously developed.

4.2 Objectives and principles for the selection of potential mariculture areas

4.2.1 Objective

Combined with the status quo of marine aquaculture development and utilization, the state of marine environment and its social and economic value, a potential aquaculture area of $3.33\times10^5 hm^2$ was selected to be suggested to carry out sustainable development of marine economy and seawater conservation in the province. To provide scientific basis for decision-making information to governments and industry departments to formulate scientific and rational marine economic development strategies and ocean policies.

4.2.2 Principles

In the selection of potential mariculture areas, the following principles should be adhered to: 1. the principle of sustainable development; 2. the principle of comprehensive planning and steady development; 3. the principle of combining development and protection; 4. the principle of forward-looking and feasibility; 5.The principle of linking with the “Marine Functional Zoning of Shandong Province”; 6. the principle of ecological suitability and environmental compliance.

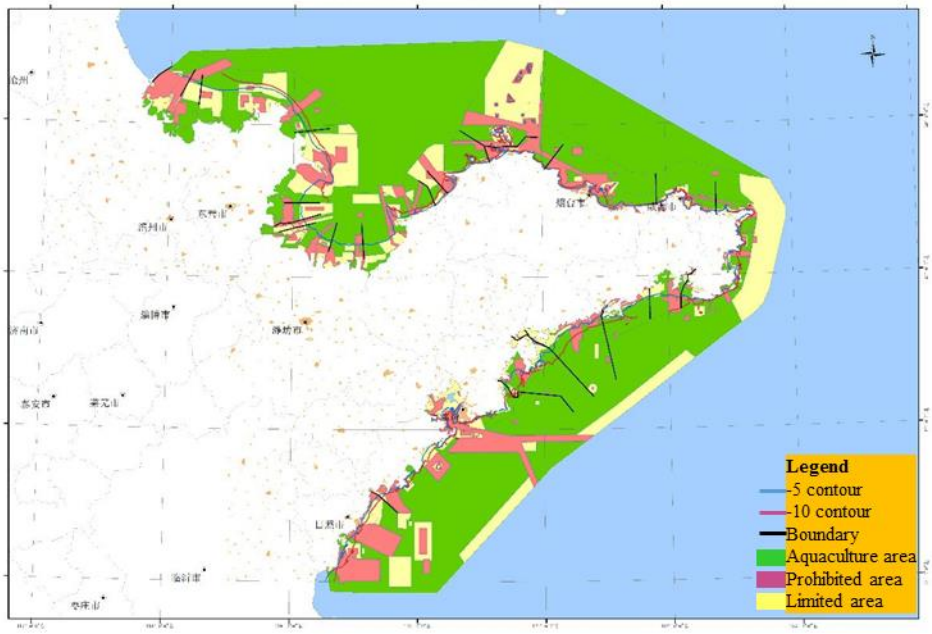

Fig. 1 Planning Map of Seashore in Mariculture Waters of Shandong Province

4.3 Typical IMTA demonstration introduction in China

4.3.1 Shellfish-seaweed and shellfish-seaweed-sea cucumber IMTA

Shellfish belong to *Mollusca*, a general name for mollusks with shells. It includes seven classes, such as lamellibranchias, gastropods, cephalopods and so on. The most widely applied species of shellfish in IMTA were mainly filter-feeding shellfish, such as oysters, scallops, mussels and herbivorous shellfish, such as abalone, etc.

The macroseaweed species (seaweed) in the integrated shellfish-seaweed culture mainly include brown seaweed *Saccharina japonica, Undaria pinnatifida, Sargassum thun bergii,* and *Sargassum fusiforme*, red seaweed *Gracilaria lemaneiformis* and *Eucheuma gelatinae*. Their biological characteristics and ecological habits vary by species.

4.3.1.1 Filter-feeding bivalves and seaweed integrated aquaculture system

According to the mutual benefit and biological characteristics of the filter-feeding bivalves and seaweed, *Saccharina* is the suitable bioremediation species during winter and spring, while *Gracilaria* is more suitable during summer and autumn.

Longline culture is mostly used in integrated aquaculture of filter-feeding bivalve and seaweed. The direction of the longline should be consistent with the direction of the seawater. The section of the longline holding the buoys or floats is called the backbone. Typically, the length of each backbone is 100 m with a 5 m gap between each other. A synthetic rope of 2.4 cm called a warp is attached to the edge of the backbone. The warp is generally three times the depth of the water. The warp is moored on the seabed by a heavy weight anchor or stake anchor. Buoys with 30 cm diameters are spaced appropriately to support the mass of growing bivalves

on the backbone. The lantern net with scallops or oysters inside are hung on the backbone. The space between the 2 lantern nets is 2.3 m with 43 units per 100 m backbones. Horizontal kelp rope cultivation is the typical method for kelp longline culture system. Each kelp rope is combined with two short kelp ropes with the length of 2.5 m. Between two adjacent floating backbones there are 174 kelp ropes parallel. The floating backbones and kelp ropes are connected by two hanging ropes and one hanging buckle. About 40 individuals of kelp are planted on each kelp rope.

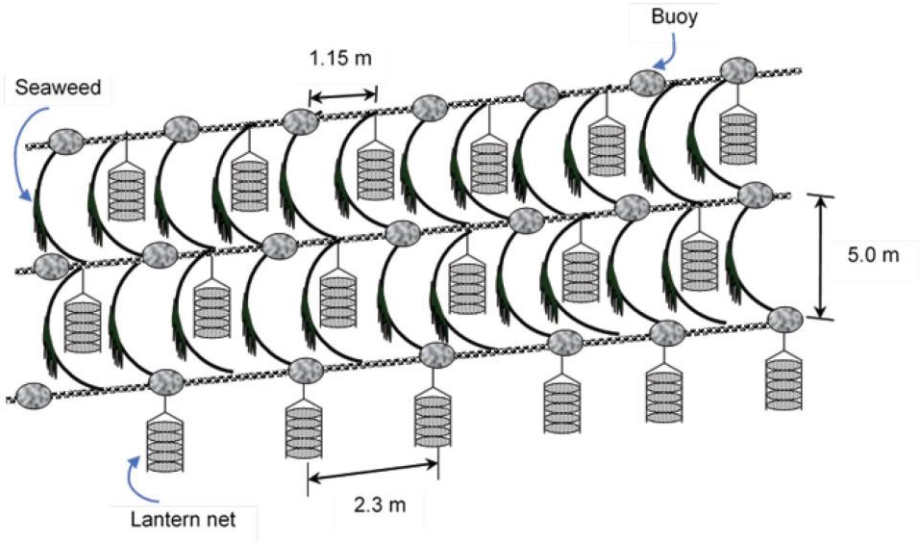

Fig. 2 The structure of longline system for shellfish and seaweed integrated aquaculture

Daily management is necessary to maintain the good growth condition of the organisms, which includes the cleaning of fouling organisms, maintaining the facilities, examining the quantities of the buoys, monitoring related environmental factors. Moreover, it is important to keep records so as to trace the products through all stages of production.

4.3.1.2 Abalone, seaweed and sea cucumber integrated aquaculture system

The abalone aquaculture needs to consume considerable artificial diet (fresh or dry seaweed). The low utilization efficiency of diet leads to the deterioration of water quality which in turn affects the health of abalone, and ultimately affecting the food production function of the aquaculture system. The implementation of abalone-seaweed-sea cucumber integrated aquaculture helps reduce the negative effects caused by large-scale abalone aquaculture significantly. In this system, the seaweed serves as the food for the abalone, while the dissolved and particle wastes generated by the abalone are taken up by seaweed and sea cucumber. The dissolved oxygen provided by the seaweed can meet the requirement of the abalone and sea cucumber.

Longline culture is mostly used in the integrated aquaculture of abalone-seaweed-sea cucumber. Each aquaculture unit consists of four lines. The length of each backbone ranges from 80-100 m with a 5m gap between each other. The facilities used for abalone aquaculture is called abalone culture cage which is hung on the backbone vertically. The cages are divided into three layers and the space between the two cages is 2.5 m with 30 cages per backbone. About 280 individuals with shell length of 3.5-4 cm of abalone are cultured on each cage. Each kelp rope is combined with two short kelp ropes with a length of 2.5 m. The kelp ropes are connected with the adjacent two backbones horizontally. About 70 individuals of kelp are planted on each kelp rope. The space between the two kelp ropes ranges from 2-3 m. The sea cucumber serves as the cleaner in this system. 2-3 individuals are cultured in each layer with the initial size of about 60-80 g per individual.

Daily management is necessary to maintain the good growth condition of the organisms which includes the cleaning of fouling organisms, maintaining of facilities, examining the quantities of the buoys, monitoring of the related environmental factors. Moreover, it is important to keep the records so as to trace the products through all stages of production.

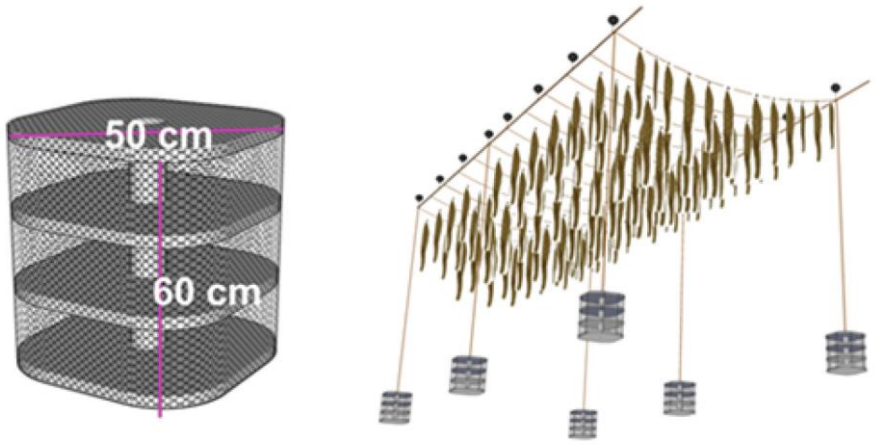

Fig. 3 The structure of longline system for abalone-seaweed-sea cucumber integrated aquaculture

4.3.2 The IMTA in pond in Northern China

The IMTA system in the northern ponds fully utilized the mutually beneficial relationship among different organisms, which not only focused on the combination of different trophic levels, but also on the utilization of different culture spaces. The functions of fish (*Lateolabrax japonicus, Pagrus major, Sparus macrocephalus, Takifugu rubripes, Mugilogobius spp* and other carnivorous fish), shrimp (*Fenneropenaeus chinensis, Litopenaeus vannamei, Penaeus japonicas* and *Exopalaemon carinicauda* etc.), crab (*Portunus trituberculatus* etc.), shellfish

(*Sinonovacula constricta, Ruditapes philippinarum, Meretrix meretrix* etc.), and other species (such as jellyfish: *Rhopilema esculenta, Rhopilema asamushi*, *Nemopilema nomurai*, and *Rhopilema hispidum*; *Stichopus japonicas; Polychaete Neanthes japonica*)were extremely utilized. Different biological characteristics and the ecological habits of species determined their functions in the pond in the IMTA system.

IMTA pond system utilizes the food chain and trophic level relationship among the ecological niches in ponds. The aquaculture organisms in the pond achieve a scientific and reasonable proportion, which can realize the full utilization of time, space, food resources and other aquaculture factors. The full use of elements should achieve the best farming effect. At the same time, it can also achieve ecological regulation and disease prevention, reduce the incidence of diseases of single-species and improve the efficiency of pond farming. For example, the filter feeding fish and shellfish are used in shrimp or fish ponds to improve the use of organic particles, feces and plankton in the ponds. Animal excrement (urine) can become a rich fertilizer for seaweed to improve water quality and reduce pollutant emissions. At present, the IMTA seawater pond is dominated by fish-sea cucumber, fish-shrimp, shrimp-crab-shellfish, and fish-shrimp-crab in northern China.

4.3.3 Pond IMTA in Zhejiang Province

Zhejiang breeds main integrated aquaculture species, including shrimp (crabs), shellfish, fish, often with any pair of breeding or multiple collocation farming. Farmers breed according to local conditions, and the pond's geographical location and conditions that are reasonable with breeding species, so as to make full use of water space and improve the utilization of nutrients.

Integrated multi-trophic aquaculture, which has merits such as high resource utilization, environmental protection, diverse product and disease prevention, etc., is a sustainable and environment-friendly culture mode. IMTA applied the ecological principles, made full use of, according to different biological niches, trophic level, diet and other differences, to regulate the culture ecosystem in the material cycle and energy flow, thereby enhancing the efficiency of materials and energy in the ecosystem to optimizing available resources. The construction of IMTA system in Zhejiang Province is characterized by local conditions. Local culture species and introduced species are organically integrated. Based on factors such as culture time, space and local climatic characteristics, an IMTA system with distinctive local features is gradually formed.

The principle of integrated culture is the reuse of farming waste. The main principle of IMTA is to change the waste discharged from one kind of cultured organism into food for another culture organism (nutrition).

Mutual benefit of culture organisms or culture systems: aquaculture organisms can be divided into feeding species (fish, shrimp, crabs, etc.) and acquired aquaculture species (filter feeding shellfish, large seaweeds, etc.). In the shrimp-shellfish polyculture system, waste feed and shrimp feces, after a variety of physical and chemical effects, are decomposed into a variety of nutrients which are absorbed by phytoplankton through photosynthesis. These phytoplankton are filtered by shellfish to achieve the purpose of waste material re-circulation.

Space collocation: first, the pond is simply divided into three parts — water, sediment surface and sediment. In order to make full use of the culture space, each part of the pond will be used to culture selected organisms according to their characteristics. Fish, shrimp and caged shellfish can be cultured in the water; bottom surface can be used for crab culture and buried habitat shellfish can be cultured in the sediment.

4.3.4 Practice of Land-based Integrated Multi-Trophic Recirculating Aquaculture Model (L-IMTRA)

Culture species could be chosen according to differences in local geography, climate and market preference. Generally, culture species should be suitable for intensive aquaculture with high economic value, e.g., turbot, grouper, black porgy, *Penaeus vannamei*, and gray mullet. Bivalves are one of the most diverse and valuable phylum Mollusca class, and they are known for removing excess phytoplankton from water. Commonly cultured bivalves include *Tegillarca granosa, Cyclina sinensis, Meretrix Meretrix, Sinonovacula constricta, Ruditapes philippinarum*, which have high economic value and water purification ability.

Based on the Niche Complementarity Theory, L-IMTRA uses aquatic species of different trophic levels to build an ecological recirculating culture pattern, and to achieve the recirculating, efficient, ecological, safe, and energy-saving purposes by optimizing the carrying capacity and regulatory measures of the system.

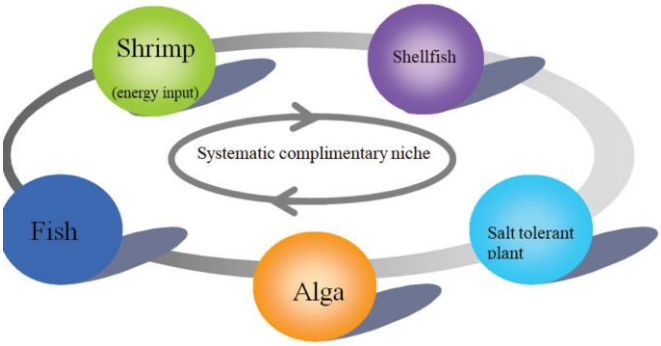

Fig. 4 The sketch map of L-IMTRA.

The seawater extracted through pumps from sea area is circulated in the system without external emissions. The aquaculture water discharged from the larvae breeding areas and high-position intensive area flows into each shellfish culture pond through circulating canals. After the removal and precipitation of seaweed and organic suspended particles (filtered by shellfish), the water flows into the wetland and finally to the ecological purifying ponds after further purification by biological, physical, chemical and other methods. After staying for some time when the zooplankton and seaweed in the water has been pumped into the sand filter ponds, the water flows back into the greenhouse and high-position intensive area for recycling in the shrimp culture and larvae breeding.

Through the coupling of multi-trophic levels of fish, shrimp, shellfish, seaweed, etc., L-IMTRA system can maximize the use of matter and energy and obtain economic benefits. Meanwhile, as aquaculture water can be recycled within the system, there is no need to pump in large amount of external waters which reduce the dependence on the external environment and alleviate the ecological impact caused by emissions. The measurement shows that the nutrient level of the aquaculture discharged water flowing back into the high-position intensive pond through circulation and sand filtration is almost equal to that of the introduced water from the sea area, from which one can see the significant purifying effect of this circulation system.

4.4 Economic analysis of benefits from replication of IMTA

According to Liu Hongmei et al. (2015), the material production value of the system under different culture models in Sanggou Bay in 2007 was estimated. The results showed that the material production value of the system under different culture models were: model 1 monoculture kelp 4.92×104 yuan/ha·a, model 2 monoculture scallop 3.14×104 yuan/ha·a, model 3 monoculture oyster 2.5 ×104 yuan/ha·a, model 4 scallops and kelp polyculture 5.93×104 yuan/ha·a, model 5 oysters and kelp polyculture 5.27×104 yuan/ha·a, model 6 kelp and abalone polyculture 3.26×105 Yuan/ha·a, model 7 kelp-abalone-sea cucumber IMTA 4.84 × 105 yuan / ha·a. The order of total value is: model 7 > model 6 > model 4 > model 5 > model 1 > model 2 > model 3; the order of environmental effect is: model 7 > model 6 > model 5 > model 1 > model 4 > model 3 > model 2; and the order of economic effect is: IMTA > polyculture > monoculture. The value provided by the IMTA is much higher than that of monoculture. For example, the food supply function service value ratio is 1.38~6.61:1 and 2.06~9.83:1, and the climate regulation function service value ratio is 1.65~2.80:1 and

1.68~2.85: 1, the service value ratio can reach up to 18:1. It can be seen that the IMTA with shellfish and seaweed as the main body can better demonstrate the ecological service function of aquaculture. The economic and ecological benefits of the IMTA models that have been established are very significant.

(1) Abalone-kelp long line IMTA: abalone aquaculture needs to consume a large number of artificial feeding baits (fresh or dried large seaweed), resulting in poor water quality, affecting the health of the cultured abalone, and ultimately affecting the food production function of the aquaculture system. The implementation of the abalone-kelp IMTA has reduced the negative effects of large-scale abalone conservation on the ecosystem. One potential benefit is to accelerate the recycling of nutrients, such as abalone feces and other excreta that can be absorbed by seaweed, while seaweed has become the food of abalone in this integrated aquaculture system. In this IMTA system, there are four long lines in each aquaculture unit, each long line is about 80 meters long, and the long line spacing is 5 meters. The total area is about 1600 square meters. Each long line can suspend 30 cages, the water depth of the cage is about 5 meters. Each cage can breed about 280 abalones with a shell length of 3.5-4 cm. The kelp hangs horizontally between abalone cages, 70 kelp can be cultured on each rope, and the distance between each kelp rope is 2-3 meters. According to abalone culture capacity, ammonia excretion rate and kelp absorption rate, a total of 33 600 abalones and 12 000 kelp integrated in one culture unit. Kelp culture begins in November and ends in June the following year. After the kelp reaches 1 meter long, it can be used for feeding abalone. The cage should be cleaned at least once a week. Under this culture mode, the abalone can reach the market specification (8-10cm) within two years. Two years later, the output of the IMTA abalone is 900kg. According to the market price in 2018, the output value can reach more than 72,000 yuan.

(2) Fish-shellfish-kelp long line IMTA: In this system, seaweed can absorb and transform inorganic nutrients excreted by fish and shellfish, and provide dissolved oxygen for fish and shellfish. Bivalves filter suspended particulate organic matter formed from fish feces, baits and phytoplankton. Using kelp and asparagus as bioremediation species from December to May (winter and spring) and July to November (summer and autumn), the nitrogen budget equation can be expressed as follows: N (seaweed) = N (fish excretion) + N (bait) + N (dead fish body). The conversion coefficients of wet and dry weight of the two species are 1:10. Nitrogen contents in dry tissues of kelp and asparagus are 2.79% and 3.42%. Yields of kelp and asparagus are 5.6 kg wet weight and 3 kg wet weight/m^2. The optimum mixture ratio for cage fish and kelp in winter and spring is 1kg (wet weight): 0.94kg (dry weight), and 1kg (wet weight): 1.53kg (dry weight) in summer and autumn. In this IMTA system, particle size plays

an important role for shellfish and other filter-feeding organisms that are capable of ingesting particulate organic matter. Pacific oysters are capable of ingesting particles less than 541 microns in diameter. The contribution of fish bait and feces to oyster food sources was proved by comparing the cage area with the non-cage area in recent experiments. The conversion efficiency of organic debris from fish culturing by oyster feeding activities is about 54.44% (10.33% of them were bait and 44.11% were feces). 41.6% of the pellet nutrients escaped from fish cages are suitable for size, oysters could assimilate and utilize 22.65% of the pellet organic matter. Bivalves play a role as cycle promoters in this system, which not only reduces pollution in aquaculture, but also generates additional income for fish farming. However, in order to achieve the greatest cleaning effect, it is necessary to match sediment feeding species (such as polychaete, sea urchin, etc.) in the system.

(3) Abalone-sea cucumber-*Ruditapes philippinarum*-*Zostera marina* bottom sowing IMTA: In this IMTA system, *Zostera marina* and *Ruditapes philippinarum* come from the natural environment. *Zostera marina* can provide food for sea urchins and abalones, and also provide shelter for other benthic or swimming organisms. Sea cucumbers can feed on abalone and clam feces, as well as natural organic sediments. Ammonia nitrogen produced by all these animals can be absorbed and utilized by *Zostera marina* and phytoplankton. Phytoplankton can provide food for *Ruditapes philippinarum.* Importantly, *Zostera marina* and phytoplankton can provide dissolved oxygen for the system. This IMTA system is located in the sea area of Chudao, in the southern part of Sanggou Bay, with a total area of 665 hectares. The main sediment of the sea area is silt, while the other submarine surface of Sanggou Bay is mainly clay. The main species of bottom-sown culture are sea cucumber, abalone, sea urchin, *Saxidomus purpuratus* and *Ruditapes philippinarum*, distributed 5-15 meters underwater. At the same time, there are a large number of naturally distributed *Zostera marina* and other seaweed in the sea area, and the seaweed covers an area of about 400 hectares. Every spring, nearly 300,000 sea urchins and 150,000 abalone seedlings are cultured in the area, and other species are naturally produced. The demonstration sea area can produce 1.5 tons of abalone, 20 tons of sea cucumber, 180 tons of *Ruditapes philippinarum*, 80 tons of *Saxidomus purpuratus*, and 2.5 tons of sea urchins. According to the price of 2018, the economic value of the product is about 12,540 yuan / hectare.

Table 4 Value of food provision service in difference aquaculture mode

Aquaculture mode	Aquacultre species	Yield kg/ha/a	Market price	Income (Y/ha/a)	Cost (Y/ha/a)	Value (Y/ha/a)

			y/kg			
monoculture	kelp	27000	6.0	162000	67500	94500
monocultue	scallop	18000	4.6	82800	22500	60300
IMTA	kelp	30000	6.0	0	72900	0
	Abalone	17308	200	1730769	1032808	697962
	Add up			1730769	1105707	625062
IMTA	kelp	30000	6.0	0	7.2900	0
	abalone	16615	200	1661538	926815	734723
	Sea cucumber	3600	120	216000	21600	204000
	Add up			1877538	948415	929123

Table 5 Value of climate regulating service in difference aquaculture mode

Aquaculture mode	Fixed & removed C (kg/ha/a)	Released CO_2 (kg/ha/a)	Value (Y/ha/a)				
			Benefit		Lost		Total value
			Reforested cost	Carbon tax	Refores ted cost	Carbo n tax	Average value
Monoculture kelp	8424.00	0	2197.82	9232.70	0	0	5715.26
Monoculture scallop	1741.17	22.35	454.27	1908.32	5.83	24.49	1166.14
IMTA kelp+abalone	23638.85	32.04	6167.38	25908.18	12.37	51.95	16005.62
IMTA kelp+abalone+ sea cucumber	24054.75	31.02	6275.88	26364.01	8.09	34.00	16298.54

4.5 Potential mariculture area selection and IMTA suitable area

4.5.1 Overview of the province

According to the characteristics of coastal zones and sea areas in the province, the selected marine aquaculture areas in the province are divided into: the Bohai Sea area in Shandong, the northern part of the Shandong peninsula, and the southern part of the Shandong Peninsula. The area of pond cultured was about 63220 hm^2, the area of bottom culture was about 294,225 hm^2, and the area of long line and cage culture was 332,309 hm^2, with a total area of 689,754 hm^2.

(1) Bohai sea area in Shandong

The coastline of this district starts from Xinhe River in Binzhou city to Jimu island Yantai City. The coastal types are mostly silt muddy, and there are about 200 tidal-flat species and more than 50 species of important economic fish and invertebrates. The near beach coating is especially suitable for shellfish growth. There are nearly 40 species of shellfish such as *Meretrix meretrix*, *Mactra veneriformis*, *Cyclina shiensis*, *Scapharca subcrenata*, *Sinonovacula constricta* among which there are more than 10 species with higher economic value.

Most of the province's pond culture areas are located in this area. It is suitable to base on the advantages of local shellfish resources, and increase the construction of standardized production demonstration bases for prawn, swimming crab (*Portunus trituberculatus*), brine shrimp and clam, and focus on the development of marine fish, sea cucumber, seaweed (such as spirulina and etc.) are suitable for demonstration and promotion of land-based IMTA model.

(2) North of Shandong Peninsula

The coastline of this area starts from Jimu Island in Longkou to the west and Rongcheng to the east. It is an important source of high-value production (such as sea cucumber and abalone) and seaweed. There are several intertidal zones with multiple narrow inner bays, and the nearshore current usually flows fast due to the geographical modification, the sediment is mostly coarse sand. A total of 344534hm^2 of potential marine aquaculture areas were selected in the region, of which 107248hm^2 was planned for the bottom culture, and 237286hm^2 for cage and long line culture.

This area is the mainly long line and cage culture area in Shandong Province. It should take advantage of the large-scale seaweed culture and expand the culture scale of high-value product such as sea cucumber, wrinkled abalone and scallop. At present, the aquaculture is concentrated in tidal flats and shallow waters, and it is suitable to promote IMTA culture models such as shellfish-seaweed-sea cucumber, shellfish-abalone-seaweed, and fish-shellfish-seaweed.

(3) South of Shandong Peninsula

The area starts from Wendeng of Weihai City in the north and Lushan District of Rizhao City in the south. The coastal topography is similar to that in the northern part of the peninsula, with the base rock harbor as the main body. There are more than 400 species of benthic organisms in the tidal areas. The total area for potential aquaculture in this region is 124,270 hm^2, of which 75,427 hm^2 for bottom culture area and 48,843 hm^2 for long line and cage culture area. This area is suitable for the development of deep-water cage fish and bottom shellfish culture. The fish-shellfish-seaweed and shellfish-seaweed IMTA systems can be considered to be promoted in this region.

4.5.2 Areas suitable for IMTA in pond in Northern China/L-IMTRA

Areas suitable for IMTA in pond in Northern China/ L-IMTRA have a total area of 63,220 hm^2, which is mainly located in the Dongtan, Binzhou and Weifang tidal flats in the Bohai Sea area of Shandong Province. It is suitable for land-based IMTA.

(1) Areas suitable for shrimp/crab-shellfish-sea cucumber IMTA in pond in Northern China/L-IMTRA

The total area in the north of yellow river is 34,420 hm^2, distributed in the coastal area of Binzhou City, Dongkou City, Hekou District, Lijin County, Kenli County at the northern part of the Yellow River and the southern shore of the Bohai Bay. Among them:

① the potential pond culture area is 25250hm^2 from Taoer river to the ancient watercourse of Yellow River, the area is suitable for the development of highly efficient standardized pond culture of *Penaeus vannamei*, Japanese prawn, Chinese prawn, three-spotted crab, sea cucumber and etc.;

② Potential pond culture in Gudong oilfield; The total area of the district is 9170hm^2, which is suitable for high-efficiency standardization of pond culture of *Penaeus vannamei*, Japanese prawn, Chinese prawn, three-spotted crab, sea cucumber and etc. It is necessary to match the filter-feeding shellfish and develop the ground-based shrimp-shellfish-sea cucumber IMTA mode in to this region.

Area in the south of yellow river is 28,800 hm^2 and is located along the coast of Laizhou Bay. The suitable seawater pond culture area is located in the extension of the existing tide-proof levee to the sea. Among them:

① Dongying City, which locates at the east of the tide-proof levee, the potential pond culture area is 12730hm^2, suitable for high-efficiency standardized pond culture, such as prawn, sea cucumber, Japanese prawn, Chinese prawn, *Portunus trituberculatus* and etc.;

② Shouguang City and the potential pond in the coastal area. The culture area is 3620 hm^2, which is suitable for cultivating the *Penaeus vannamei*, sea cucumber, Japanese prawn, Chinese prawn, and three-spotted crab. It is necessary to pair the filter-feeding shellfish to develop the land-based IMTA model of shrimp-crab-shellfish-sea cucumber.

The area in Changyi is 12450hm^2, which is located in the southern part of Laizhou Bay. It is suitable for aquaculture of species as *Penaeus vannamei*, Japanese prawn, Chinese prawn, three-spotted crab, sea fish and sea cucumber. It is necessary to pair with cultured filter-feeding shellfish to develop a land-based IMTA model of shrimp-crab-shellfish.

4.5.3 Bottom culture

(1) Regional IMTA Bottom culture

The total area of Bohai area in Shandong Province is about 111550hm^2. Among them:

① The potential bottom-casting culture area in the southern part of the Bohai Bay is 29,690hm^2, suitable for shellfish culture and nursing, the major species includes *Meretrix meretrix, Mactra veneriformis, Cyclina shiensis, Perinereis aibuhitensis, Sinonovacula constricta, Potamocorbula amurensis, Scapharca subcrenata, Neverita didyma, etc.*;

② The potential bottom-aquaculture area in the eastern part of the island is 13930hm^2, which is suitable for the aquaculture of *Meretrix meretrix, Mactra veneriformis, Cyclina shiensis, Ruditapes philippinarum, Perinereis aibuhitensis, Sinonovacula constricta, Potamocorbula amurensis, Scapharca subcrenata, Neverita didyma, Crassostrea gigas, etc.*;

③ The potential suitable area near Dongying city is 18650hm^2, which is suitable for the culture of *Meretrix meretrix, Mactra veneriformis, Cyclina shiensis, Ruditapes philippinarum, Perinereis aibuhitensis, Sinonovacula constricta, Potamocorbula amurensis, Scapharca subcrenata, Neverita didyma, Crassostrea gigas etc.*;

④ The potential bottom breeding area between Xiaoqinghe to Qimu Island is 49280hm^2, which is suitable for the aquaculture of *Meretrix meretrix, Ruditapes philippinarum, Mactra veneriformis, Scapharca subcrenata, Solen grandisDunker, Cyclina shiensis, Potamocorbula amurensis, Neverita didyma, etc.* The shellfish cultured downstream of the ponds. Shellfish bottom culture is helpful to reduce the seawater eutrophication from the ponds and increase carbon sequestration.

(2) Shellfish-seaweed-sea cucumber bottom IMTA in north of Shandong Province

The total area in north of Shandong Province is 107,248 hm^2, mainly located around the islands of Long Island, Penglai and Chengdao, and also in the northern waters of Weihai City. Among them:

① The potential bottom culture area near Sangdao island is 703hm^2, which is suitable for high value products such as *Stichopus japonicus, Haliotis discus hannai, Chlamys farreri, Patinopecten yessoensis* and other shallow sea bottom culture;

② The potential suitable area for offshore deep-water bottoming culture at longdao island and penglai island is 40809hm^2, which is suitable for bottom-breeding of high value products such as *Patinopecten yessoensis, Stichopus japonicus, and Haliotis discus hannai*.

③ The potential bottom culture area in the east of the Kongtong islands is 4249hm^2, suitable for breeding sea cucumbers. It is famous in China as one of the origins of sea cucumber aquaculture;

④ The potential bottom culture area in the northern part of Weihai City is 17115hm^2, suitable for the culture of high value products such as *Stichopus japonicus, and Haliotis discus hannai*;

⑤ The potential bottom- casting area in the north of Rongcheng City is 17750hm^2, suitable for breeding *Patinopecten yessoensis, Stichopus japonicus, and Haliotis discus hannai*.;

⑥ The area of potential bottom culture in the south of Rongcheng City is 26,625 hm^2, which is suitable for the cultivation of *Patinopecten yessoensis, Stichopus japonicus, and Haliotis discus hannai*.

These areas are suitable for the promotion of the integrated culture model of the shellfish-seaweed-sea cucumber. The seaweed bed could be established.

(3) Shellfish-seaweed-sea cucumber bottom IMTA

The total area in the south of Shandong Province is 75,427 hm^2, which is mainly distributed in the waters of Wendeng, Rushan, Haiyang, Jimo and in the southeastern part of Lushan Mountain. Among them:

① The area of potential bottom culture area in the southern part of Weihai City is 25,631 hm^2, suitable for the culture of *Ruditapes philippinarum, Mactra chinensis, Scapharca broughtonii, Stichopus japonicus, etc.*;

② The potential bottom culture area in the southern part of Haiyang City is 20238hm^2, suitable for *Ruditapes philippinarum, Mactra chinensis, Scapharca broughtonii, Stichopus japonicus, Haliotis discus hannai, etc.*;

③ The potential bottom-casting area in the southern part of Jimo City is 17038hm^2, suitable for bottom culture of *Ruditapes philippinarum, Saxidomus purpurata, Mactra chinensis, Meretrix meretrix, Stichopus japonicus* and other places;

④ To the east of Laoshan mountain in the sea, the potential bottom culture area is 903hm^2, which is suitable for the culture of *Stichopus japonicus, Haliotis discus hannai, Ruditapes philippinarum, Saxidomus purpurata, Scapharca broughtonii, etc.*;

⑤ The potential bottom culture area near Lingshan island is 4843 hm^2, suitable for the culture of *Ruditapes philippinarum, Saxidomus purpurata, Atrina pectinata, Stichopus japonicus, Haliotis discus hannai, etc.*;

⑥ The potential bottom culture area at the estuary of the 2 cities is 3533hm^2, suitable for culture of *Ruditapes philippinarum, Saxidomus purpurata, Mactra veneriformis, Atrina pectinata, Solen grandisDunker, Scapharca broughtonii,* and *Stichopus japonicus*;

⑦ The potential deep-water bottom culture area of the qiansandao island is 3421hm^2, which his suitable for the culture of *Ruditapes philippinarum, Saxidomus purpurata, Atrina pectinate, Solen grandisDunker, Stichopus japonicus, Haliotis discus hannai, etc*.

This area and its adjacent waters are suitable for the promotion of the IMTA model of Shellfish-Seaweed-sea cucumber and Abalone-seaweed-sea cucumber.

4.5.4 Shallow sea aquaculture

(1) Shellfish-Seaweed-sea cucumber IMTA

Shallow sea area in the Bohai sea region is about 46180 hm^2. Among them:

① The area of potential shallow sea culture area around Furong Island is 13080hm^2. At present, the area has not been developed on a large scale, and it is mainly suitable for *Argopecten irradians* and *Chlamys farreri*;

② The potential long line culture area from Sanshan Island to Qidao in Laizhou City is 33098hm^2, which is suitable for *Argopecten irradians, Chlamys farreri,* and *Crassostrea gigas*culture.

This area and its adjacent waters are suitable for the promotion of the IMTA model of Shellfish-Seaweed-sea cucumber and Abalone-seaweed-sea cucumber.

(2) Shellfish-Seaweed / Shellfish-Seaweed-sea cucumber IMTA

The suitable area in the north of Shandong Peninsula is 237286hm^2, which is mainly distributed around Long Island, Penglai islands, Kongdong islands and the sea area around Weihai City and Rongcheng City. Among them:

① Shellfish-Seaweed IMTA: The area of the potential bottom culture area near Longkou City is 9579hm^2, which distributed in the east (3659hm^2) and west (5920hm^2) side of the Sangdao island. It is suitable for shellfish culture, such as *Argopecten irradians* and *Chlamys farreri.*

Shellfish-Seaweed-sea cucumber IMTA:

② The potential deep-water long line and cage culture area near Changdao County is 57,803 hm^2, which is suitable for culture scallops *(Chlamys farreri, Patinopecten yessoensis, Argopecten irradians), Haliotis discus hannai*, sea urchin, *Pacific oysters,* kelp, *etc.*;

③ Penglai City, Yantai Development Zone the potential long line culture area is 29,293 hm^2, which is suitable for shellfish and seaweed**,** such as scallops *(Chlamys farreri, Patinopecten yessoensis, Argopecten irradians), Haliotis discus hannai***,** purple mussels**,** kelp, sea urchins**,** Pacific oysters, etc.;

④ The potential long line culture area near kongtong island is 1388hm^2, which is suitable for scallops (*Chlamys farreri, Patinopecten yessoensis, Argopecten irradians*), kelp, Pacific oysters, etc.;

⑤ The potential long line culture area in the northern sea of Weihai is 15128hm^2. The exisit culture species are kelp and wakame, scallops (*Chlamys farreri, Patinopecten yessoensis, Argopecten irradians*), purple mussels, sea urchins, etc.;

⑥ Rongcheng city's northern deep sea waters aquaculture area is 24,691 hm^2, the kelp and wakame are the major culture species, this region also raise scallops (*Chlamys farreri, Patinopecten yessoensis, Argopecten irradians*), purple mussels, sea urchins, etc.;

⑦ The potential deep-water aquaculture area in the eastern waters of Rongcheng City is 99403hm^2, with kelp and wakame being the major culture species, and it can also raise scallops (*Chlamys farreri, Patinopecten yessoensis, Argopecten irradians*), purple mussels, sea urchins, and etc.

This area and the nearby sea area are suitable for the promotion of IMTA mode of shellfish-seaweed, shellfish-seaweed-sea cucumber, and abalone-seaweed-sea cucumber.

(3) Shellfish-Seaweed / Shellfish-Seaweed-sea cucumber/ Fish-Shellfish-Seaweed IMTA

The total area in the southern part of the Shandong Peninsula is 48843hm^2, mainly distributed in the southern part of Rushan, Qingdao, Jiaonan and Rizhao offshore. The water depth is from 6-30m with sandy and rocky sediment. The water flows with moderate speed, the wind and waves are small, the water quality is good with no pollution. The water is rich in

plankton and moderate nutrient salt which mostly are estimated to be class I water quality. Among them:

① The area of the long line and cage culture area in the southern part of Rushan City is 12143hm^2, suitable for scallops, Purple mussels, Pacific oysters, kelp and caged sea cucumbers, wrinkled abalone, *Sebastes schlegeli*, *Hexagrammos otakii*, *Lateolabrax japonicus*, etc.;

② The potential long line-cage culture area is 2514hm^2 near the Laoshan bay, suitable for long line culture scallops, purple mussels, Pacific oysters, kelp and caged sea cucumber, wrinkled abalone, etc. And cage culture *Sebastes schlegeli*, *Hexagrammos otakii*, *Lateolabrax japonicas*, etc.;

③ The potential cage culture area near Lingshan bay is 3245hm^2, suitable for long line culture of scallops, purple mussels, Pacific oysters, kelp and caged sea cucumber, wrinkled abalone, etc. This area is also suitable for cage culture of *Sebastes schlegeli*, *Hexagrammos otakii*, *Lateolabrax japonicus*, etc.;

④ The potential long line and cage culture area near Taohua islands in Rizhao city is 8939hm^2, which is suitable for kelp, wakame, stripe laver and scallop, Pacific oysters, purple mussels, etc.;

⑤ The potential sea area for long line and cage culture near Qiansandao Island is about 22002hm^2, which is suitable for the culture of scallops, kelp, wakame and pacific oysters. The cooresponding cage culture can be deployed for sea bass, *Sebastes schlegeli*, *Sciaenops ocellatus* and so on.

This area and its adjacent waters are suitable for IMTA mode promotion such as shellfish-seaweed-sea cucumber, abalone- seaweed-sea cucumber and fish-shellfish-seaweed.

Table 6 Suitable area for IMTA in Shandong Provence

Suitable IMTA mode	**District**	**Area (hm^2)**	**Sediment**	**Suitable species for IMTA**
Land-based IMTA, need to increase shellfish species, or to form a regional IMTA with shellfish aquaculture	ancient watercourse of Yellow River	25250	silt and muddy	*Penaeus vannamei, Stichopus japonicu, Penaeus japonicus, Portunus trituberculatus*
	Gudong oilfield	9170	silt and muddy	*Penaeus vannamei, Stichopus japonicu, Penaeus japonicus, Portunus trituberculatus*
	eastern part of Dongying district	12730	silt and muddy	*Penaeus vannamei, Stichopus japonicu, Penaeus japonicus, Portunus trituberculatus*

	Shouguang City	3260	silt and muddy	*Penaeus vannamei, Stichopus japonicu, Penaeus japonicus, Portunus trituberculatus*
	Changyi City	12450	silt and muddy	*Penaeus vannamei, Penaeus japonicus, Fenneropenaeus chinensis, Portunus trituberculatus*, sea fish, *Stichopus japonicu,*
Bottom sowing of shellfish is beneficial to reduce eutrophication of seawater and increase carbon sequestration. Regional IMTA can be formed with pond culture	southern part of the Bohai Bay	29690	silt and muddy	*Meretrix meretrix, Mactra veneriformis, Cyclina shiensis, Perinereis aibuhitensis, Sinonovacula constricta, Potamocorbula amurensis, Scapharca subcrenata, Neverita didyma*
	eastern part of Gudao, Dongying City	13930	silt and muddy	*Meretrix meretrix, Mactra veneriformis, Cyclina shiensis, Ruditapes philippinarum, Perinereis aibuhitensis, Sinonovacula constricta, Potamocorbula amurensis, Scapharca subcrenata, Neverita didyma, Crassostrea gigas*
	eastern part of Dongying City	18650	silt and muddy	*Meretrix meretrix, Mactra veneriformis, Cyclina shiensis, Ruditapes philippinarum, Perinereis aibuhitensis, Sinonovacula constricta, Potamocorbula amurensis, Scapharca subcrenata, Neverita didyma, Crassostrea gigas*
	Qimu Island	49280	silt and muddy	*Meretrix meretrix, Ruditapes philippinarum, Mactra veneriformis, Scapharca subcrenata, Solen grandisDunker, Cyclina shiensis, Potamocorbula amurensis, Neverita didyma*
Regional Shellfish-Seaweed-sea cucumber IMTA	Sangdao Island	703	bedrock	*Patinopecten yessoensis, Stichopus japonicus, Haliotis discus hannai*
	Dilai	40809	bedrock	*Patinopecten yessoensis, Stichopus japonicus, Haliotis discus hannai*
	east of the Kongtong islands	4249	bedrock, sand	*Stichopus japonicus*

	northern part of Weihai City	17115	bedrock	*Stichopus japonicus, Haliotis discus hannai*
	north of Rongcheng City	17750	bedrock	*Patinopecten yessoensis, Stichopus japonicus, Haliotis discus hannai*
	south of Rongcheng City	26625	sand, bedrock	*Patinopecten yessoensis, Stichopus japonicus, Haliotis discus hannai*
	southern part of Weihai City	25631	sand	*Ruditapes philippinarum, Mactra chinensis, Scapharca broughtonii, Stichopus japonicus*
Shellfish-Seaweed-sea cucumber IMTA	southern part of Haiyang City	20238	sand, bedrock	*Ruditapes philippinarum, Mactra chinensis, Scapharca broughtonii, Stichopus japonicus, Haliotis discus hannai*
	southern part of Jimo City	17038	silty sand	*Ruditapes philippinarum, Saxidomus purpurata, Mactra chinensis, Meretrix meretrix, Stichopus japonicus*
	islands in the eastern part of Laoshan mountain	903	bedrock	*Stichopus japonicus, Haliotis discus hannai, Ruditapes philippinarum, Saxidomus purpurata, Scapharca broughtonii*
	Lingshan island	4843	bedrock	*Ruditapes philippinarum, Saxidomus purpurata, Atrina pectinata, Stichopus japonicus, Haliotis discus hannai*
	the estuary of the 2 cities	3353	silt and muddy	*Ruditapes philippinarum, Saxidomus purpurata, Mactra veneriformis, Atrina pectinata, Solen grandisDunker, Scapharca broughtonii, Stichopus japonicus*
	Qiansandao island	3421	bedrock	*Ruditapes philippinarum, Saxidomus purpurata, Atrina pectinate, Solen grandisDunker, Stichopus japonicus, Haliotis discus hannai*
Shellfish-Seaweed-sea cucumber and Abalone-seaweed-sea cucumber IMTA	around Furong Island	13080	sand	*Argopecten irradians, Chlamys farreri*
	Qidao	33098	sand	*Argopecten irradians, Chlamys farreri, Crassostrea gigasculture*
	northern part of Longkou City	9579	sand	*Argopecten irradians, Chlamys farreri*

	Changdao County	57803	bedrock, sand	*Chlamys farreri, Patinopecten yessoensis, Argopecten irradians, Haliotis discus hannai, Echinoidea, Crassostrea gigas, Laminaria japonica*
	Yantai Development Zone	29293	bedrock, sand	*Chlamys farreri, Patinopecten yessoensis, Argopecten irradians, Haliotis discus hannai, Mytilus edulis, Laminaria japonica, Echinoidea, Crassostrea gigas*
	Kongtong island	1388	bedrock	*Chlamys farreri, Patinopecten yessoensis, Argopecten irradians, Laminaria japonica, Crassostrea gigas*
	northern sea of Weihai	15128	bedrock	*Laminaria japonica, Undaria pinnatifida, Chlamys farreri, Patinopecten yessoensis, Argopecten irradians, Mytilus edulis, Echinoidea*
	northern waters of Rongcheng City	24691	bedrock	*Laminaria japonica, Undaria pinnatifida, Chlamys farreri, Patinopecten yessoensis, Argopecten irradians, Mytilus edulis, Echinoidea*
	eastern waters of Rongcheng City	99403	bedrock	*Laminaria japonica, Undaria pinnatifida, Chlamys farreri, Patinopecten yessoensis, Argopecten irradians, Mytilus edulis, Echinoidea*
Shellfish-Seaweed-sea cucumber, Abalone-seaweed-sea cucumber and Fish-Shellfish-Seaweed IMTA	southern part of Rushan City	12143	sand, bedrock	*Pectinidae, Mytilus edulis, Crassostrea gigas, Laminaria japonica,* and caged *Stichopus japonicus, Haliotis discus hannai, Sebastes schlegeli, Hexagrammos otakii, Lateolabrax japonicus*
Fish-Shellfish-Seaweed IMTA	Laoshan bay	2514	silt and muddy	long line culture *Pectinidae, Mytilus edulis, Crassostrea gigas, Laminaria japonica,* and cage culture *Stichopus japonicus, Haliotis discus hannai, Sebastes schlegeli, Hexagrammos otakii, Lateolabrax japonicus*

Fish-Shellfish-Seaweed IMTA	Lingshan bay	3245	silt and muddy	*Sebastes schlegeli, Hexagrammos otakii, Lateolabrax japonicus*
Fish-Shellfish-Seaweed IMTA	Taohua islands	8939	silt and muddy	long line culture *Laminaria japonica, Undaria pinnatifida, Porphyra yezoensis, Pectinidae, Crassostrea gigas, Mytilus edulis,* or cage culture *Sebastes schlegeli, Hexagrammos otakii, Lateolabrax japonicus, Sciaenops ocellatus*
	Qiansandao Island	22002	bedrock, sand	long line culture *Pectinidae, Laminaria japonica, Undaria pinnatifida, Crassostrea gigas,* deep water cage culture *Sebastes schlegeli, Lateolabrax japonicus, Sciaenops ocellatus*