Chapter 9

The Natural Ecology and Stock Enhancement of the Edible Jellyfish (*Rhopilema esculentum* Kishinouye, 1891) in the Liaodong Bay, Bohai Sea, China

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Abstract

Among the edible jellyfish species, *Rhopilema esculentum* Kishinouye, 1891, is one of the most abundant jellyfish species consumed. Therefore, this jellyfish species is an important fisheries source in China. The jellyfish fisheries in China show annually considerable fluctuations and have a very short season. In the chapter, we firstly try to review the natural ecology of *R. esculentum*, which includes the distribution and migration, growth model, and survival rate in the Liaodong Bay (LDB) based on the results of our field studies for more than 20 years. Secondly, we focus on reviewing the jellyfish fishery and population dynamic in the LDB. Thirdly, we emphasize the themes, including the survey methods, catch prediction, enhancement assessment, and fishery management, based on our survey results from 2005 to 2010. Finally, we present our field and experiment results of resource restoration. The high commercial value of *R. esculentum* enhancement in the LDB has made this a very successful enterprise.

Keywords: *Rhopilema esculentum*, distribution, population dynamic, jellyfish fishery, enhancement and releasing

1. Introduction

Several species of scyphozoan jellyfish with mild stings are considered to be edible jellyfish. They are also used for medicinal purposes, such as treatment of high blood pressure, bronchitis, and a multitude of other diseases. They have been caught commercially and exploited along the coasts of Indian, Northwest Pacific, and Western Central Pacific Oceans by several countries, such as Thailand, Indonesia, Malaysia, the Philippines, Japan, South Korea, and China for over a thousand years [1–5]. Among the edible species, *Rhopilema esculentum* Kishinouye, 1891, is the most abundant and important species in the Asian jellyfish fishery. In particular, large edible jellyfish aggregates around the river mouth, and *R. esculentum* in the order Rhizostomae, are considered to be delicacy food in Chinese cooking. The Chinese have commercially exploited the jellyfish along the coasts of China for over a thousand years, and the jellyfish industry has become a commercial fishery. For these reasons, *R. esculentum* was selected as the species to be cultured and released for commercial harvest [1, 6, 7].

Despite its importance as a commodity, scientific studies in Southeast Asia have lagged behind the rapid development of exploitation [5]. But, in China, scientists paid more attention to the biology and fishery of edible jellyfish; a series of research projects have been carried out over 20 years for the purpose of commercial development. The research results on *R. esculentum* from the author's team only cover life cycle, experimental ecology, natural ecology, and stock enhancement, including distribution and locomotion, stock structure, growth model, feeding habit, and catch prediction [8–18].

In addition, the technology of artificial breeding, pond culture, and stock enhancement in nature was further developed along the coastal waters of northern China [6, 7, 19, 20]. In China, the Liaodong Bay (LDB) of Bohai Sea is one of the most important jellyfish fishing grounds, and the jellyfish fisheries in the Bay is characterized by considerable fluctuations in the catch, varying from about 400 tons to 290,000 tons, and including a short fishing season. The earliest enhancement experiment was put in practice in 1984 for the purpose of stabilizing and increasing catches. From 1984 to 2004, the tentative stock enhancement has been conducted for 11 times [6, 7, 19–21], and from 2005 to 2010, the large-scale stock enhancement of jellyfish (*R. esculentum*) was carried out for the first time in LDB where 157–365 million juvenile jellyfish (bell diameter of >1.00 cm) per year were released.

In this chapter, the natural ecology of *R. esculentum* in the LDB, based on our field and experiment study for more than 20 years, is reviewed. In the meantime, the large-scale release of cultured jellyfish, fishery forecast, and jellyfish fisheries management is presented.

2. Life cycle and environmental adaptation of *R. esculentum*

Researches on the life cycle of *R. esculentum* have been conducted since the 1970s [11] (**Figure 1**). The medusae are dioecious. Fully, developed oocytes are released into open seawater and fertilization and embryogenesis occur subsequently. Cleavage of the zygote is total and equal. A hollow blastula is formed 5–6 h after fertilization at 21.0–23.0°C. Gastrulation occurs by invagination. A total of 7–8 h after fertilization, actively swimming planula larvae appear in experimental conditions. Most of the planula larvae metamorphose into scyphistomae with four tentacles in 3–4 days and scyphistomae eventually occur with 16 tentacles in 15–20 days. During the course and after full growth, the scyphistomae continuously form podocysts. It is a way of asexual reproduction. Two months later, strobilation occurs at

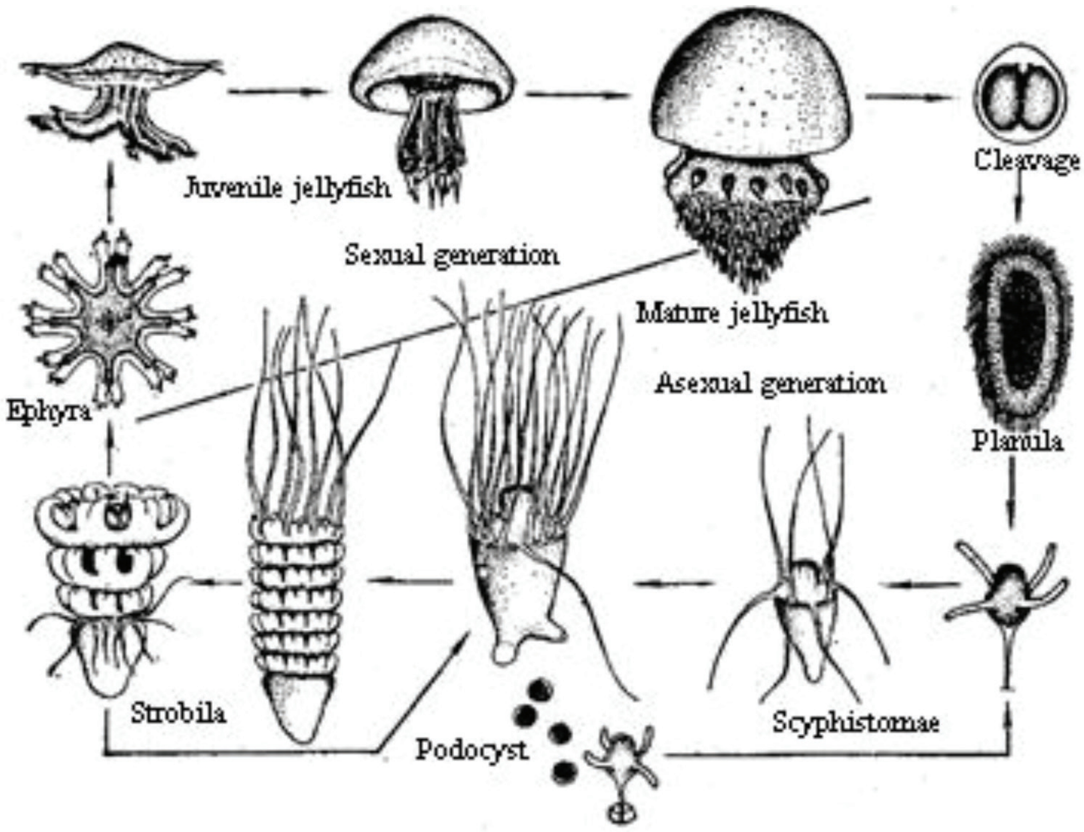

Figure 1. Life cycle of *Rhopilema esculentum* Kishinouye, 1891 [11].

18.0–20.0°C. Generally, a strobila produces 6–10 ephyra larvae. The ephyra larvae reach to about 20.0 mm in diameter in about 15 days in the laboratory and may attain 50.0 mm in diameter within 30 days. In the LDB, ephyra larvae grow into mature jellyfish 250–450 mm in diameter in 2–3 months.

The life cycle of *R. esculentum* is similar to those of *Nemopilema nomurai* Kishinouye, 1922, and *Rhopilema hispidum* (Vanhöffen, 1888). The ephyra larvae of *N. nomurai*, *R. esculentum,* and *R. hispidum* are differentiated by different shapes of lappet, rhopalar cleft, gastric cirrum, and nematocyst battery [12, 22].

The asexual reproduction methods, strobilation regulation, and mechanism of artificial control have been demonstrated. On the basis of life history in previous periods, the feeding habits (i.e. prey taxonomic group, size), feeding rate, and growth rate of medusae and scyphistomae were examined. In the meantime, effects of physical factors (i.e. temperature, salinity, light, food, pollution, fish activity) on different development stages of jellyfish *R. esculentum* were studied [8–10, 13, 14, 17, 18, 23]. The main conclusions are as follows: Suitable weak light can stimulate planula metamorphosis, while dark conditions promote podocyst excystment, and the survival rate of polyps decreases with increasing light intensity. The podocysts do not excyst below 10.0°C and the excystment rate increases between 15.0 and 30.0°C. Increasing temperature from 2.00–10.0°C to 22.0°C in winter induces strobilation in 2 weeks. A scyphistoma produces 7–8 ephyra larvae, on average. The optimal growth temperature for ephyra larvae is 24.0°C, with a favorable range of 16.0–28.0°C. No podocysts are produced when salinity is less than 6 psu; the optimum salinity range for podocyst generation is from 20.0 to 22.0 psu. Planula larvae of *R. esculentum* are the most favorable food for its early scyphistomae, while trochophores (trochophore larvae) of shellfish (*Crassostrea gigas* Thunberg, 1793) and blastula larvae of sea urchins (*Hemicentrotus pulcherrimus* A. Agassiz, 1864) are food supplements for early scyphistomae. Fully developed scyphistomae, ephyra larvae, and young medusae can be fed with *Artemia* spp. nauplii and zooplankton.

3. Natural ecological habit of *R. esculentum*

3.1. Distribution of *R. esculentum* in China

R. esculentum is a common large jellyfish, which is the warm-water estuarine species in China, and this species can provide adaptation to a wide range of water temperatures and salinity. The main habitat of this species in China was from the Yalu River estuary in the north to the area of Beibu Gulf in the south. In addition, *R. esculentum* is also found in the Western Japan, Southern Korean peninsula, and Russia Far East. The habitats of juvenile *R. esculentum* are estuarine regions, where they grow and reproduce. Because of the temperature variations based on the differences in various geographical locations, the breeding season and the moving route of *R. esculentum* in different marine ecosystems are not the same. In coastal areas extending from the South to the North of China, there are many geographical *R. esculentum* populations, such as Eastern Guangdong, Southern Fujian, Eastern Fujian, Southern Zhejiang, Hangzhou Bay, Haizhou Bay, Laizhou Bay, Bohai Bay, and Liaodong Bay populations [7].

3.2. Distribution and locomotion of *R. esculentum* in the Liaodong Bay

The northern part of the LDB is covered by ice blocks in winter and a high proportion of polyps over winter and they carry out strobilation in the next spring. With regard to juvenile and young medusae liberated by strobilation near their native environments, there are large amounts of researches in the LDB, including on the stock structure, growth model, geographic, and seasonal distribution and population dynamics carried out by Li et al. [15, 16], Liu et al. [24], and Dong et al. [7]. More information on distribution, migration, growth, and optimum fishing season of the jellyfish species should be obtained in order to select releasing sites and establish an adequate catch prediction model before the fishing season.

Horizontal distribution and habitat depth of the *R. esculentum* population in the LDB is related to their ecological characteristics. Juveniles of *R. esculentum* tolerate salinity values of 10–20 psu; adult jellyfish tolerate salinity values of 12–35 psu; and their optimal salinity value is 23–28 psu [10, 23]. *R. esculentum* have a sensitive sensation which can move vertically across different layers of water. This species often floats above the water during the calm dawn and evenings or cloudy days, whereas they inhabit in the bottom or near the bottom during the night and day with wind, storm, and rapids. This vertical movement behavior of jellyfish based on its sensitive sensation in the phylogeny is of great significance for maintaining the survival of population and relative stability of habitat.

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Due to being a planktonic species, the moving ability of *R. esculentum* is weak; hence, the wind, wind direction, currents, and tides can affect the distribution of jellyfish. As a relatively independent stock, *R. esculentum* of the LDB mainly shows a distribution in the waters, both sides of 5-m isobaths, and its amount accounts for more than 90.0% of the total resources in the LDB. Juveniles of *R. esculentum* all occur near the estuarine regions in early and mid-June. *R. esculentum* mainly appears in the 5-m isobaths near the estuaries of Shuangtaizi, Daling, Xiaoling, and Liao Rivers (**Figure 2**). Areas of dense jellyfish distribute in different estuaries and coastal waters in different years. Compared to late June, the jellyfish uniformly distribute in early July in the estuarine waters, which still mainly concentrate in the 5-m isobaths. More jellyfish are also found in the 5–10-m isobaths during the year.

In mid- and late July, distribution of jellyfish *R. esculentum* is still concentrated within the 10-m isobath. But its abundance in the 5–10-m isobaths tends to spread slightly toward deeper waters or other layers where less jellyfish are found. In different years, the center fisheries' jellyfish zone extends from the Liao River to the Daling and Xiaoling River and even to inshore of Jinzhou.

When compared, ecological characteristics and migration patterns of two important large jellyfish species *R. esculentum* and *N. nomurai* inhabited in the LDB are different from each other. Dong et al. [7, 22] showed that the salinity range of 20.0–27.5 psu is the most appropriate

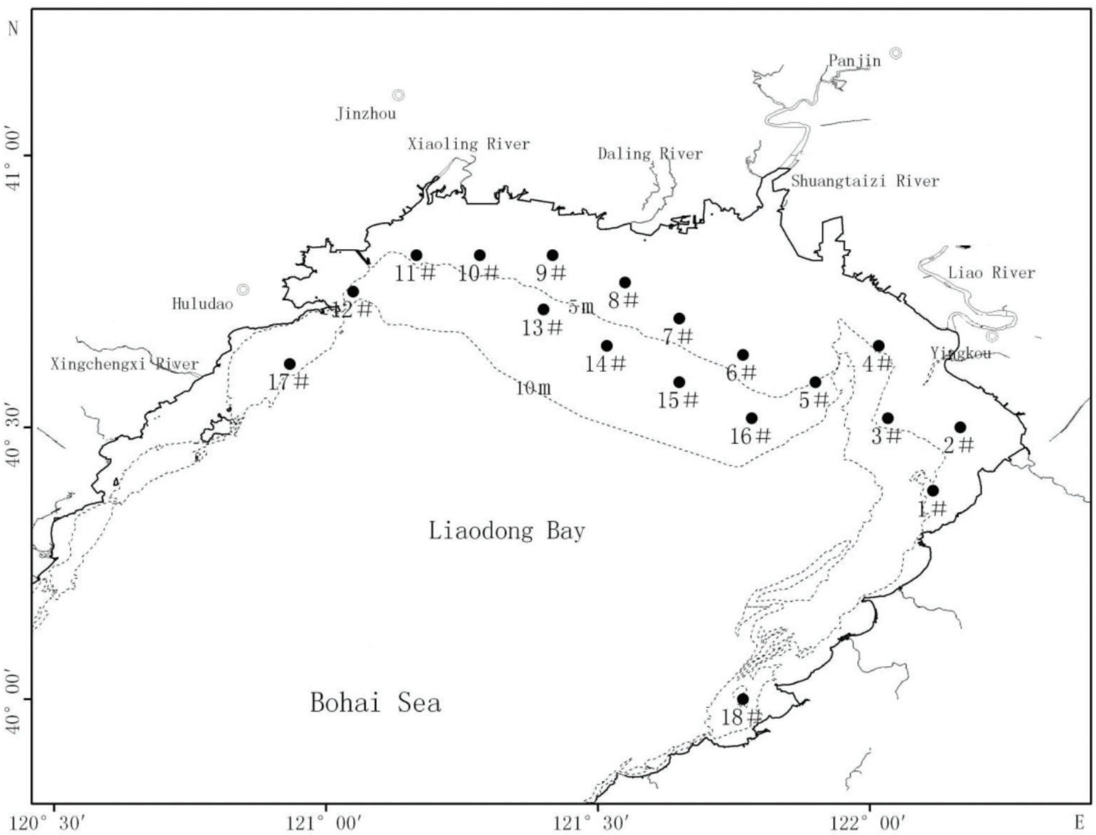

Figure 2. Survey sites of *Rhopilema esculentum* Kishinouye, 1891 in the Liaodong Bay during 2005–2010.

for *N. nomurai* podocyst reproduction, survival and somatic growth of polyps, and asexual production of podocysts. The optimum salinity range is in the range of 20.0–22.0 psu for podocyst generation of *R. esculentum* and 14.0–20.0 psu for survival of planula larvae [18, 23]. Juveniles of both species all are found in the estuary and shallow coastal areas, where there are low-salinity and high-temperature values (T 20.4–24.4°C and S 24.7–31.6 psu). But as the season progresses, *N. nomurai* becomes bigger and more mature and this restricted distribution expands to the whole LDB or advances to the southern Liaodong peninsula [25]. However, jellyfish *R. esculentum* inhabit the coastal waters of the 5–10-m isobaths of the LDB throughout [7, 26].

3.3. Growth model of *R. esculentum*

The growth model of the jellyfish *R. esculentum* is very important in order to predict the best fishing season. Since the jellyfish shrink after the first 10 days (10 d) of September without asymptotic values, it is impossible to show the growth pattern of jellyfish by means of regular asymptotic growth equation [15]. Its growth pattern may be described with a polynomial expression as a function of time, as follows:

$$L_t = 0.2198 + 0.4146\,t + 0.2203\,t^2 + 0.03824\,t^3 - 0.002249\,t^4. \quad (1)$$

L_t designates the arc length of the jellyfish swimming bell; t is time in 5-d units, beginning on June 20 (t_0) when the strobilae of jellyfish release ephyra larvae in the field. The correlation is significant according to the F test statistic ($F = 4126 > F_{0.005}(1, 9) = 13.61$).

4. Stock enhancement history of *R. esculentum*

4.1. Experimental release of cultured jellyfish

The tentative stock enhancement efforts were conducted 11 times between 1984 and 2004 by Liaoning Ocean and Fisheries Science Research Institute with the aim of stabilization and increase of the jellyfish fisheries. During 1984–1986, 2.00×10^5, 5.0×10^5, and 2.10×10^5 ephyra larvae (bell diameter of 5.00–15.0 mm) were released into the northern Yellow Sea from June to July each year. The recapture rate was estimated to be 1.20–2.50%.

The numbers from 4.60×10^6 to 1.73×10^7 of ephyra larvae (bell diameter of 5–10 mm) were released in the Dayang River estuary on the northern Yellow Sea during 1988–1993. The annual recapture rate ranged from 0.07 to 1.02%.

In 2002, 1.20×10^6 juveniles (bell diameter of 20 mm) were released into Jinpu Bay, the northern Yellow Sea, where the recapture rate was estimated to be 1.20%.

In 2004, 5.30×10^6 juveniles were released to the coastal waters near to the Dayang River estuary, the northern Yellow Sea. The jellyfish catch was 79.0 tons throughout the jellyfish fishing season with each individual averaging 7.00 kg wet weight. The recapture rate was about 0.20%.

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Year	Released time (day/month)	Released size BD (mm)	Released amount (10^8 ind.)
2005	25–30, May; 16–25, June	≥10.0	1.57
2006	12–20, June	≥10.0	2.58
2007	16–25, June	≥10.0	2.50
2008	16–25, June	≥10.0	3.00
2009	01–07, June	≥10.0	3.18
2010	01–07, June	≥10.0	3.65

BD: bell diameter.

Table 1. Releasing records of ***Rhopilema esculentum*** Kishinouye, 1891, in Liaodong Bay during 2005–2010.

4.2. Large-scale release of jellyfish culture

Based on the life history, the technology of artificial breeding was researched and developed. We concluded that abundant juvenile jellyfish can be obtained in a very short time by adjusting the physical factors (light, temperature, salinity, and food) in jellyfish culture. During 2005–2010, yearly, over 500 million juvenile jellyfish produced by polyps in the previous year were raised to more than 20 breeding centers. The total volume of artificial breeding tanks for juveniles was about 30,000–40,000 m^3 in Liaoning Province. Steady and high-efficiency production capability of juvenile jellyfish establishes the foundation for large-scale stock enhancement of jellyfish.

During 2005–2010, the large-scale release and enhancement of *R. esculentum* were conducted by the Ocean and Fisheries Bureau of Liaoning Province in the LDB of the Bohai Sea, where 157–365 million juvenile jellyfish (bell diameter of >1 cm) were yearly released. In breeding centers, juveniles which will be released were transferred into plastic bags with oxygen-saturated sea water and were released into natural waters of 3–5-m depth. Young *R. esculentum* jellyfish individuals were released into the northern coastal areas of the LDB near Huludao, Jinzhou, Panjin, Yingkou, and Wafangdian cities. The Jellyfish individuals were all released during 01 June–25 June (for Jinzhou in 25–30 May, 2005), when their bell diameters were 1 cm, similar to those in nature. The released juveniles immediately mixed with the natural jellyfish comprising a mixed stock (**Figure 2**; **Table 1**).

5. Population dynamic survey and output forecast

5.1. Survey of released jellyfish

Mixed jellyfish stock monitoring was undertaken in late May, from early to mid-June, late June, from early to mid-July, and from mid- to late July between 2005 and 2010 in order to determine the survival, growth, and recapture rates of the released jellyfish. Eighteen survey sites within the 10-m isobaths were established in the juvenile jellyfish habitat of the LDB. The sites from 1 to 11 were within the 5-m isobaths, and the others at 5–10-m isobaths. As jellyfish grew, drift nets of different mesh size were used: dense mesh net (60 m length × 8 m height, 1 cm mesh size); middle mesh net (60 m length × 7 m length, 3 cm mesh size); and giant jellyfish net (60 m length × 8 m length, 10 cm mesh size) (**Figure 2**).

5.2. Various sources of mortality

The numbers of released jellyfish decreased due to various mortalities over time. It is very important to estimate how to reduce mortality during the whole developmental process from the beginning of release to the end of fishing season. It is helpful for managers to decide on appropriate measures to improve the efficiency of enhancement. Four different causes of mortality are listed in **Table 2**: (i) Handling mortality (M_1): In the period when the jellyfish were transferred into plastic bags full in oxygen, transported, and released in the natural waters, handling mortality occurred; (ii) Abrupt mortality (M_2): It occurred during 2–3 days after the cultured juvenile jellyfish were released into the sea, resulting from the sudden change of physical conditions and preys and so on; (iii) Natural mortality (M): It is caused by a combination of factors, including predation, competition, disease, and changes in environmental conditions during 40–50 days from the end of June to the beginning of fishing season; And (iv) Unlawful fishing mortality (F): Jellyfish death was caused by fishing with various kinds of nets before the fishing season opened. According to the various mortality experiments of 2005 and 2006, various mortalities were estimated by Ye et al. [1] and Dong et al. [7]. The average handling mortality was estimated as 6.00%, the abrupt mortality was 79.0%, and the average natural mortality was 55.0% of the jellyfish surviving after release. But the percentage of this unlawful fishing mortality is very difficult to estimate.

5.3. Catch forecast

The basic method of catch forecast is to survey the relative abundance with high-efficiency fishing drift nets in late June and early July. Eighteen sites were established in the main jellyfish fishing areas. The relative abundance is the average number of jellyfish caught on 1 net

t	number	BD (cm)	Mortality
t_0	N_0	1.0	↓ M_1: Handling mortality.
t_1	N_1	1.0	↓ M_2: Abrupt mortality.
t_2	$R_1 = N_2 + R_0$	3.0	↓ F: Unlawful fishing mortality.
t_3	R_2	16.0 to 49.4	↓ M: Natural mortality
t_4	$Y=Y_1 + Y_2$		

N_0 = released number; N_1 and N_2= number of released jellyfish surviving at different stages; R_0 = natural jellyfish stock; R_1 = mixed stock composed of released jellyfish and natural jellyfish; Y = total yield caught in fishing season; Y_1 and Y_2 = catch of natural jellyfish and released jellyfish; BD = bell diameter; t_0 = releasing time; and t_4 = fishing season.

Table 2. Mortality characters of the jellyfish ***Rhopilema esculentum*** Kishinouye, 1891, in the Liaodong Bay.

in 1 3-h catch. The catch forecast is obtained based on the model of relative abundance and fishing effort. The original forecasting equation was reported by Li et al. [16]:

$$Y = -17{,}963 + 98.2x_1 + 4.6x_2. \tag{2}$$

where Y = the forecasting output; x_1 = relative abundance; and x_2 = fishing effort. This relationship is significant (R = 0.97; standard deviation S = 2898; F = 31.57 > $F(4, 2)_{0.005}$ = 26.28).

From 2005 to 2010, the number of fishing vessels has been constant and had little effect on catch. The forecast catch was based on the relative resource only briefly [7]:

$$Y = -8580 + 1019.6\,(9.97 + 0.424x). \tag{3}$$

where Y = the forecasting output; x = relative abundance; and statistical test results were significantly correlated at 0.05 level (R = 0.85).

6. Jellyfish fisheries and management

6.1. Fishing ground and fishing methods

In **Figure 2**, the survey areas show the main fishing ground of about 5000 km^2, and it is located in the northern part of 40°30′N with 5–10-m depth. The actual fishing areas are smaller than the real area, and there are about 10,000 fishing boats in the narrow area in blooming year. At the jellyfish fishing season, there are two fishing boats per square km. In the years of low yield or no-releasing jellyfish year, fewer fishing vessels engaged in fishing production.

The fishery is characterized by large fluctuations of the annual catch and a short fishing season that has lasted only 2–3 days in recent years. From 2005 to 2010, edible jellyfish enhancement was carried out in the LDB, and the government participated in the management of jellyfish resources. The production of jellyfish in the LDB was maintained at the level of 15.7–91.0 thousand tons, and the output value was 173–546 million Yuan. In the years without releasing jellyfish, 2010–2017, the output of jellyfish in LDB dropped to less than 2000 tons (**Table 3**).

The jellyfish fishing grounds where great numbers of edible jellyfish occur are characterized by having a large tidal range, shallow depth, semi-enclosed waters, fresh water inflow through river systems, low salinity, and abundant foods. Fishing gear used includes various trawls, set nets, drift nets, push nets, and hand nets. The most efficient drift nets that were set at a depth of 2–10 m are placed across the current flow with a system of floats and sinkers. The length of each net is 30–50 m, with height of 8–12 m. A vessel loads 10–30 nets, which depends on the power of the vessel. The optimal jellyfish fishing period is 10–20 August. Because fishermen were eager for jellyfish fishing, and the fishing season generally advances at the end of July to early August.

	Year	Output (10^3 ton)	Number of fishing boats	Price (Yuan/kg)	Value (10^6 Yuan)
Releasing jellyfish year	2005	91.0	10000*	6	546
	2006	30.9	10,367	7	216
	2007	33.6	11,469	7	235
	2008	17.5	10,427	10.8	186
	2009	23.5	9461	10	235
	2010	15.7	6156	11	173
No releasing jellyfish year	2011	1.0	2061	16.6	17
	2012	1.3	2020	15.3	19
	2013	0.5	636	10	5
	2014	0.4	737	10.5	4
	2015	0.6	649	6.7	4
	2016	0.5	714	6.8	3.4
	2017	0.08	531	5.6	4.4

Table 3. Edible jellyfish (***Rhopilema esculentum*** Kishinouye, 1891) fishery in the Liaodong Bay from 2005 to 2017.

7. Evaluation of releasing effect

From 2005 to 2010, a total of 1.648 billion jellyfish were released by proliferating in the LDB. The average recapture rate of releasing is 1.77%, and 25.24 million jellyfish were recaptured. The individual weight was ca. 1.50–2.50 kg and recapture output was 48,500 tons which accounted for 22.86%of total edible jellyfish harvest during 2005 and 2010. Higher economic benefits were created, as much as 334.37 million Yuan (**Table 4**).

Year	Recapture amount (10^4ind.)	Recapture rate (%)	Recapture output* (10^4 t ind.)	Recapture value (10^4 Yuan)
2005	502	3.20	1.25	7500
2006	807	3.13	1.60	7200
2007	527	2.11	0.32	3000
2008	306	1.02	0.28	2267
2009	214	0.67	1.08	10,000
2010	168	0.46	0.32	3470
Total	2524	1.77	4.85	33,437

*Output counted as unprocessed fresh jellyfish.

Table 4. Evaluation on releasing effect of ***Rhopilema esculentum*** Kishinouye, 1891, in the Liaodong Bay during 2005–2010.

8. Habitat protection area in Liaodong Bay

According to the survey data for the jellyfish over the years, the concentrated distribution area of juvenile *R. esculentum* was within the 5-m isobaths of Shuangtaizi, Liao, Daling, and Xiaoling estuary.

Jellyfish were distributed in the 10-m isobaths in the northern part of the LDB; hence, the water area in the 10-m isobaths may be the habitat of jellyfish which can be delimited as the habitat protection area. In the protection areas, juvenile *R. esculentum* appeared more frequently from the Shuangtaizi to Daling estuaries. Therefore, it is speculated that the concentrated distribution area of *R. esculentum* polyps was from the Shuangtaizi to the Daling estuaries. The pink color area in **Figure 3** between Shuangtaizi and Daling estuaries was marked as the core area of jellyfish habitat protection area. The light blue water in the 5-m isobaths was designated as the buffer zone for the jellyfish habitat protection area. The water within the 5–10-m isobaths (gray) was delimited as the experimental area for the jellyfish habitat protection area.

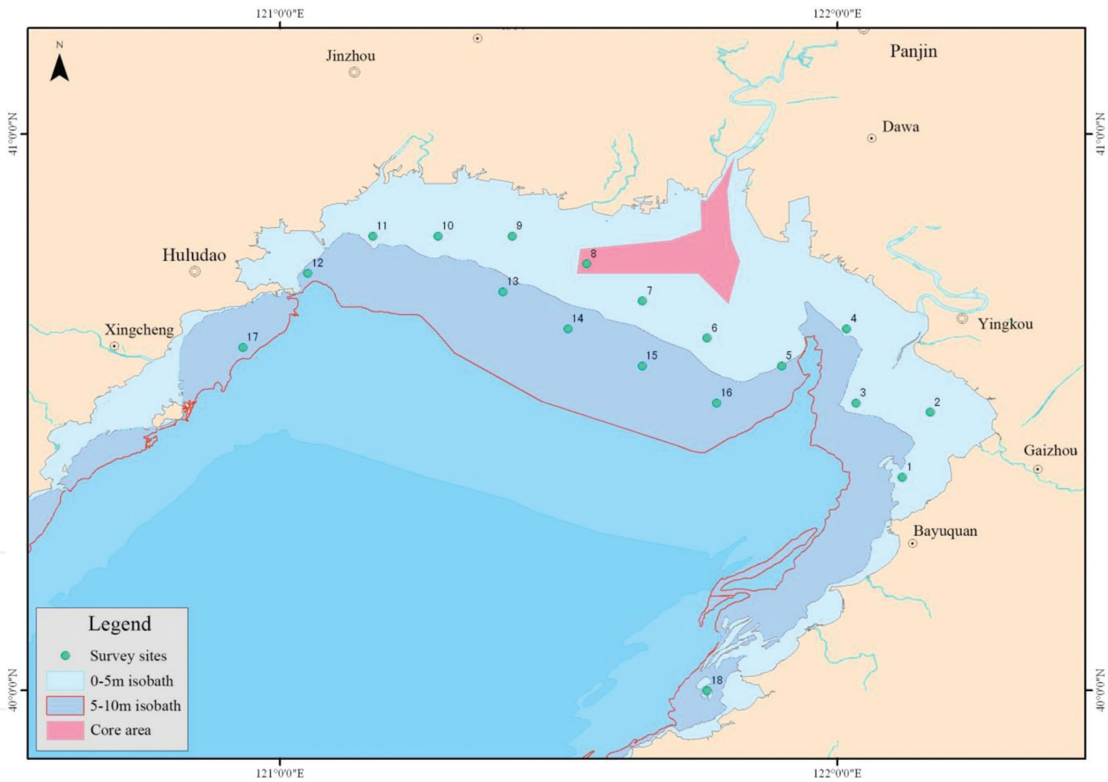

Figure 3. The habitat protection area of *Rhopilema esculentum* Kishinouye, 1891, polyp in the Liaodong Bay.

9. Discussion on the reasons for the decline of quantity

9.1. Effect of marine engineering and trawl net

In recent years, the marine engineering construction and trawl net caused damage for habitat of *R. esculentum* polyp. In LDB coastal waters, the fisherman catch crabs, conch, fish, benthic shellfish, and other economic categories using the trawl, dredge net, and pump, which can damage the habitat of *R. esculentum* polyp. Moreover, many human activities such as the port expansion, waterway dredging, and reclamation could occupy the habitat of *R. esculentum* polyp. The floating mud caused by these human activities may also cause the death of polyp in natural sea water, which reduces the number of jellyfish polyp in the natural sea water, affecting the production of jellyfish in the coming year in the LDB.

9.2. Effect of runoff on the resources of jellyfish in LDB estuary

Ye et al. [1], Jiang et al. [26], and Dong et al. [7] have used the variable runoff, the occurrences of wind and temperature, and the relative abundance to study the effects of these factors on the number of jellyfish in the LDB. The results showed that runoff was the most important factor that affected the number of jellyfish in the LDB.

9.3. Effect of the first catching time for jellyfish

The most juvenile *R. esculentum* individuals appeared in mid- and late June in the LDB. The time of sexual maturity for medusa is late August and early September in the LDB. Hence, according to the growth of jellyfish, the August and early September is the appropriate first catching time of jellyfish. In recent years, the first catching time of jellyfish was in late July for 9 consecutive years. Basing on the gonads' dissection, the jellyfish gonads were not yet fully mature in late July. Moreover, jellyfish are dioecious, and there is the mutual induction process between ovulation and fertilization. Studies by Dong et al. [27] have proved that the interactions among mature individuals in jellyfish were very important for ovulation and fertilization. Therefore, in late July, the proportion of sexual reproduction may be low in nature water. The premature catching time of jellyfish could reduce the jellyfish fishing yields and economic benefits, and affect the number of jellyfish polyps, thereby affecting the number of jellyfish in the next year.

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