Acta Oceanol. Sin., 2022, Vol. 41, No. 12, P. 80–86
https://doi.org/10.1007/s13131-022-2057-6
http://www.aosocean.com
E-mail: ocean2@hyxb.org.cn

Long-term and monthly changes in abundance, size composition and spatial distribution of the mantis shrimp *Oratosquilla oratoria* in the Bohai Sea

Qiang Wu[1, 2], Qingpeng Han[1, 3], Yue Jin[1, 2], Tao Yang[1, 2], Zhongyi Li[1, 2], Xiujuan Shan[1, 2, 3]*, Xianshi Jin[1, 2]

[1] Key Laboratory for Sustainable Development of Marine Fisheries, Ministry of Agriculture and Rural Affairs/ Shandong Provincial Key Laboratory for Fishery Resources and Eco-environment, Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Qingdao 266071, China

[2] Laboratory for Marine Fisheries Science and Food Production Processes, Pilot National Laboratory for Marine Science and Technology (Qingdao), Qingdao 266237, China

[3] Fisheries College, Ocean University of China, Qingdao 266003, China

Received 24 June 2021; accepted 23 June 2022

Abstract

With the decline in fish resources worldwide, the ecological dominance and economic importance of crustaceans have obviously increased. Among crustacean species, mantis shrimps are increasingly dominant in many coastal waters of the world. In China, *Oratosquilla oratoria* is the most widely distributed and productive species of mantis shrimp, and its relative resource density is the highest in the Bohai Sea. In this study, we analysed the long-term and monthly population characteristics of *O. oratoria* in the Bohai Sea, including its relative resource density, body size and spatial distribution. The results showed that the relative resource density of *O. oratoria* in the Bohai Sea increased from 3.59 kg/h in 1982 to 14.48 kg/h in 2018, and the percentage of this species that serves as a fishery resource increased from 4.22% in 1982 to 35.27% in 2018, based on the mean relative resource density in May and August. The relative resource density of *O. oratoria* in the fishing moratorium season from May to August was significantly higher than that in the other months of fishing season, and the relative resource density decreased rapidly after the fishing moratorium ended. The relative resource density of *O. oratoria* was the highest in summer (August), followed by in autumn (October) and spring (May), and it was the lowest in winter (January). The relative resource density of *O. oratoria* in the western Bohai Sea was higher than that in the eastern Bohai Sea. The mean body weight of *O. oratoria* in the Bohai Sea decreased from 21.95 g in 1982 to 14.34 g in 2018, based on the mean body weight in May and August. The body size of *O. oratoria* in the fishing moratorium season was significantly higher than that in the fishing season, and the body size decreased rapidly after the fishing moratorium ended. Overall, in the context of declining resources of most fishery species, the relative resource density of *O. oratoria* increased due to its hardiness and adaptability, and its body size decreased under intensive fishing over the past 30 years. The fishing moratorium system had a great influence on the population dynamics of *O. oratoria* in terms of the relative resource density and body size in the Bohai Sea.

Key words: long-term and monthly changes, population dynamics, mantis shrimp *Oratosquilla oratoria*, Bohai Sea

Citation: Wu Qiang, Han Qingpeng, Jin Yue, Yang Tao, Li Zhongyi, Shan Xiujuan, Jin Xianshi. 2022. Long-term and monthly changes in abundance, size composition and spatial distribution of the mantis shrimp *Oratosquilla oratoria* in the Bohai Sea. Acta Oceanologica Sinica, 41(12): 80–86, doi: 10.1007/s13131-022-2057-6

1 Introduction

Crustaceans are important marine organisms and play important roles in marine ecosystems. In addition, most crustacean species have important commercial value, such as Decapoda and Stomatopoda (mantis shrimp), providing a large amount of high-quality proteins for humans. With the decline in fish stocks, the ecological and economic importance of crustaceans has increased in global fisheries (Tully et al., 2003). The global catch of marine crustaceans in 2016 was 79.6% higher than that in 1990, much higher than that of cephalopods (+52.9%), bottom marine fish (+3.7%) and pelagic marine fish (−13.0%) (Boenish et al., 2022). Among crustacean species, mantis shrimp (Stomatopoda) are renowned as major and commercially valuable fisheries resources in coastal countries, especially in some Asian countries (Colloca et al., 2003; Kodama et al., 2004; Garces et al., 2006; Lui et al., 2007; Antony et al., 2010). In China, *Oratosquilla oratoria* is the most widely distributed and productive species of mantis shrimp, which lives throughout China's coastal areas (Deng et al., 1988). Compared with the Yellow Sea, East China Sea and South China Sea, the Bohai Sea has the highest density of *O. oratoria* (Deng et al., 1988). The Bohai Sea is China's inland sea and the spawning grounds for various fishery species, and large amounts of nu-

Foundation item: The National Key Research and Development Program of China under contract No. 2018YFD0900902; the Central Public-Interest Scientific Institution Basal Research Fund, Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, under contract Nos 2022YJ01 and 2021TD01; the Special Funds for Taishan Scholar Project of Shandong Province.
*Corresponding author, E-mail: shanxj@ysfri.ac.cn

trients are discharged by more than 40 rivers (including the Huanghe River) into the sea, promoting primary productivity and providing abundant food organisms (Deng et al., 1988; Jin, 2000; Wu et al., 2019).

Unfortunately, the Bohai Sea has suffered from intensive anthropogenic activities and intensive fishing, obviously affecting its habitats and living resources. As a consequence of multiple stressors, including overfishing, environmental pollution, marine engineering construction and climate change (Jin, 2003; Jin et al., 2013; Li et al., 2013), fishery production and the community structure of fishery stocks in the Bohai Sea have changed greatly (Jin, 2004), with ecologically dominant species shifting from large groundfishes at high trophic levels in the 1950s to small pelagic fishes in the 1980s (Deng et al., 1988; Jin, 2000) and then to small groundfishes and invertebrates at low trophic levels in recent years (Wu et al., 2017). With the decline in fish stocks, the proportion of economically important invertebrates has increased, such as *O. oratoria,* which has become the biomass-dominant species in the Bohai Sea (Wu et al., 2016b).

Although *O. oratoria* is becoming the dominant species in the Bohai Sea, its long-term and inter-monthly changes in population dynamics have not been reported. In this study, the changes in the relative resource density, body size and spatial distribution of *O. oratoria* in the Bohai Sea were analysed using long-term survey data collected since 1982 and monthly survey data collected from 2013 to 2019. We also discussed the impact of fishing effort and fishing moratorium systems on the relative resource density and body size of *O. oratoria* in the Bohai Sea. The above research aims to provide a scientific basis for the sustainable utilization of *O. oratoria* in the Bohai Sea.

2 Materials and methods

2.1 *Sampling area and time*

Figure 1 shows the survey area of Bohai Sea. All data were obtained from bottom trawl surveys conducted by the Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Science. Each survey was conducted in the daytime to avoid the effect of diel vertical movements on catchability. Long-term survey data were obtained from the spring (May) and summer (August) surveys in the Bohai Sea from 1982 to 2018. Although the number and spatial distribution of the sampling stations slightly differed in different years, all the surveys covered the same areas of the Bohai Sea. Monthly survey data were obtained in different months from 2013 to 2019. The number and spatial distribution of the sampling stations were the same in different months.

2.2 *Fishing vessels and gears*

The same paired trawlers have been used in the surveys since 1982, with the same type of fishing gear. The gears had a codend mesh size of 2 cm, a headline height of 5–6 m and a distance of 22.6 m between wings. Detailed descriptions of the sampling protocol were reported by related studies (Deng et al., 1988; Tang et al., 2003; Jin, 2004). All the biomass data from the surveys were standardized for 1 h for each station.

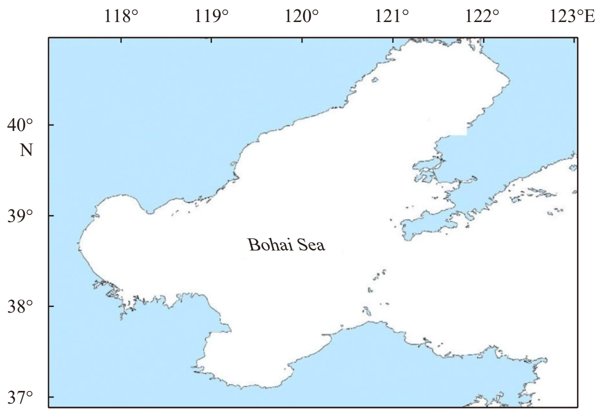

Fig. 1. The survey area of Bohai Sea.

2.3 *Individual size*

2.3.1 *Body weight*

Mean body weight was used to indicate the individual size of *O. oratoria*. The mean body weight of *O. oratoria* in a survey was obtained by dividing the total biomass by the total number of individuals. The individual numbers of *O. oratoria* caught for the mean body weight in May and August from 1982 to 2018 are shown in Table 1. The individual numbers of *O. oratoria* caught for the mean body weight in different months of 2017 are shown in Table 2.

2.3.2 *Body length*

The body lengths of the randomly selected samples of *O. oratoria* in different months from 2013 to 2019 were measured. The mean body length of the randomly selected samples represents the individual size of *O. oratoria*. The number of randomly selected samples in different months from 2013 to 2019 are shown in Table 3.

3 Results

3.1 *Changes in relative resource density*

Figure 2 illustrates the long-term changes in relative resource density and the percentage of *O. oratoria* accounting for the fishery resources by bottom trawling in the Bohai Sea. Overall, the relative resource density of *O. oratoria* in the Bohai Sea increased from 3.59 kg/h in 1982 to 14.48 kg/h in 2018, based on the mean relative resource density in May and August. The bio-

Table 1. The number of *Oratosquilla oratoria* used to obtain the mean body weight in May and August from 1982 to 2018

Survey time (May/Year)	1982	1993	1998	2004	2010	2013	2014	2015	2016	2017	2018
Individual number	3 854	3 522	3 241	830	190	57	614	3 228	5 832	50 985	8 193
Survey time (August/Year)	1982	1992	1998	2009	2010	2013	2014	2015	2016	2017	2018
Individual number	14 920	13 368	1 822	31 975	1 877	723	21 804	20 977	33 180	51 331	66 606

Table 2. The number of *Oratosquilla oratoria* used to obtain the mean body weight in different months of 2017

Survey time	March	April	May	June	July	August	September	October	November
Individual number	610	1 435	50 985	39 580	72 400	51 331	16 072	10 068	3 123

Table 3. The number of randomly selected samples for body length in different months from 2013 to 2019

Year	March	April	May	June	July	August	September	October	November
2013	–	–	–	–	–	180	–	–	–
2014	–	–	–	115	–	–	–	–	–
2016	–	–	–	–	–	–	–	865	–
2017	101	372	1 131	1 696	1 486	1 576	199	448	431
2018	–	–	1 357	–	–	–	–	49	–
2019	–	–	216	175	1 098	1 024	–	–	–

Note: – represents no data.

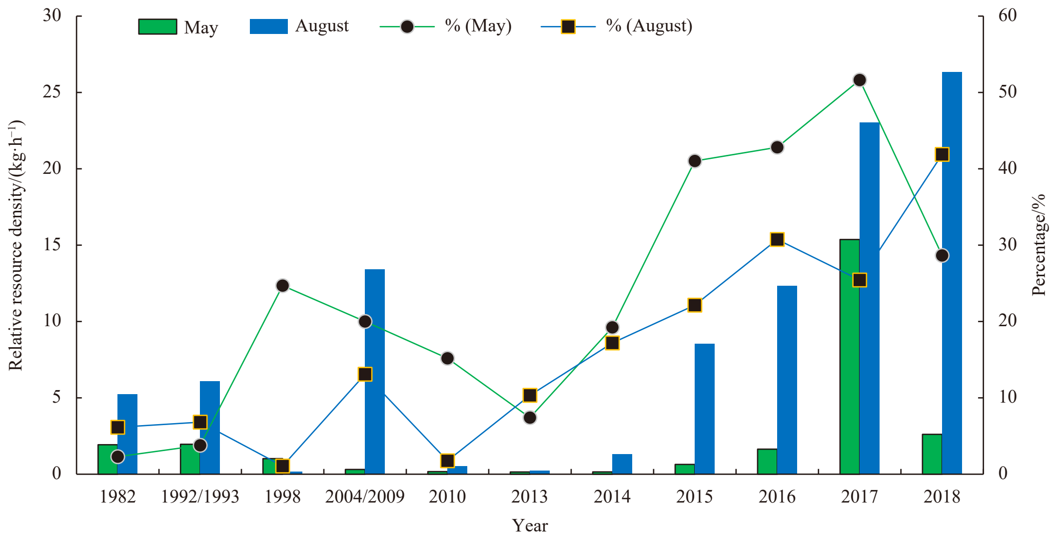

Fig. 2. Long-term changes in relative resource density and the percentage of *Oratosquilla oratoria* accounting for the fishery resources in the Bohai Sea from 1982 to 2018.

mass densities in August were significantly higher than the biomass densities in May (*P*<0.05). The percentage of *O. oratoria* accounting for the fishery resources in the Bohai Sea showed a similar trend to that of relative resource density, and the overall trend was rising, except for the relatively low level from 2010 to 2013. The mean percentages in May and August increased from 4.22% in 1982 to 35.27% in 2018.

Figure 3 shows the monthly changes in relative resource density of *O. oratoria* in the Bohai Sea from March to November 2017. The relative resource density of *O. oratoria* in the Bohai Sea varied between 0.08 kg/h and 29.75 kg/h. The biomass densities of *O. oratoria* from May to August in the fishing moratorium season were significantly higher than those in other months in the fishing season (*P*<0.01), and the density increased rapidly from

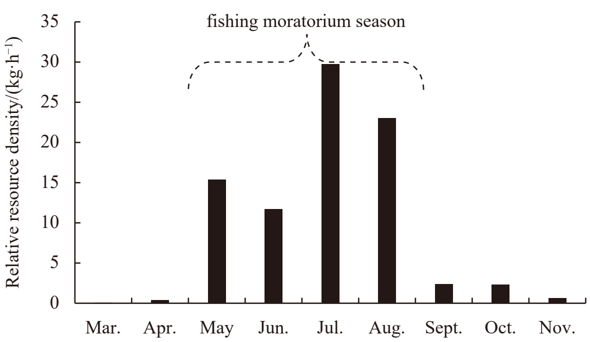

Fig. 3. Monthly changes in biomass densities of *Oratosquilla oratoria* in the Bohai Sea in 2017. The fishing moratorium season is from May 1 to September 1.

0.38 kg/h in April to 15.37 kg/h in May and declined sharply from 20.03 kg/h in August to 2.37 kg/h in September.

3.2 *Changes in body size*

3.2.1 *Body weight*

Figure 4 illustrates the long-term changes in the mean body weight of *O. oratoria* in the Bohai Sea from 1982 to 2018. The mean body weight of *O. oratoria* showed a downward trend, regardless of it being May or August. In May, the mean body weight of *O. oratoria* decreased from 23.73 g in 1982 to 9.00 g in 1998, then increased to 23.87 g in 2010, and gradually decreased to 12.42 g in 2018. In August, the mean body weight of *O. oratoria* decreased from 20.16 g in 1982 to 13.71 g in 2010 and then fluctuated to 16.28 g in 2018. Overall, the mean body weight of *O. oratoria* in the Bohai Sea decreased from 21.95 g in 1982 to 14.34 g in 2018, based on the mean body weight in May and August.

Figure 5 shows the monthly changes in the mean body weight of *O. oratoria* in the Bohai Sea in 2017. The mean body weight of *O. oratoria* showed a continually upward trend from 4.15 g in March to 17.95 g in August, and then, it dropped sharply to 7.07 g in September and remained low in October and November.

3.2.2 *Body length*

Figure 6 illustrates the body length of *O. oratoria* in the Bohai Sea in different months from 2013 to 2019. The proportion of individuals with longer body lengths increased gradually from March to August, which indicated that *O. oratoria* grew continuously in body length. However, the proportion of individuals with longer body lengths dropped sharply from September to Novem-

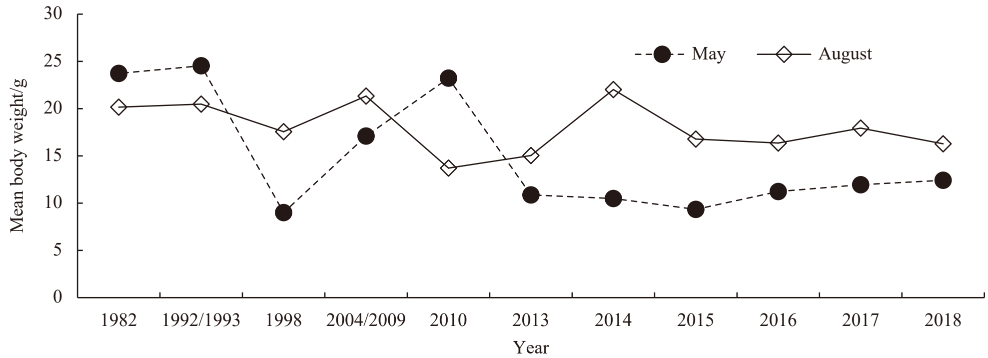

Fig. 4. Long-term changes in the mean body weight of *Oratosquilla oratoria* in the Bohai Sea.

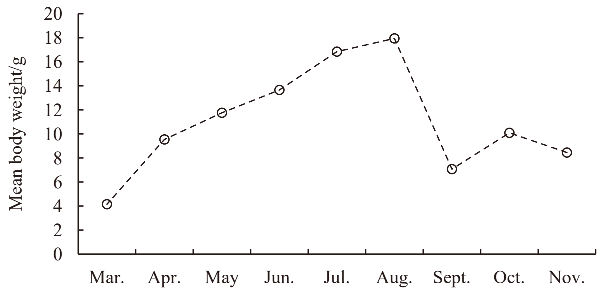

Fig. 5. Monthly changes in the mean body weight of *Oratosquilla oratoria* in the Bohai Sea in 2017.

ber when the fishing moratorium season ended.

3.3 *Changes in spatial distribution*

Figure 7 showed the long-term and seasonal changes in the spatial distribution of *O. oratoria* in the Bohai Sea. In spring (May), the density of *O. oratoria* was higher from 1982 to 1998 than from 2004 to 2015 and increased rapidly from 2016 to 2018. The density of *O. oratoria* was higher in the middle of the Bohai Sea and Laizhou Bay than in other areas in spring from 1982 to 2018. In summer (August), the density of *O. oratoria* was higher from 1982 to 1992 than from 1998 to 2014 (except in 2009), and it increased rapidly from 2015 to 2018. The density of *O. oratoria* was higher in the middle of the Bohai Sea and some coastal waters than in other areas in summer from 1982 to 2018. In autumn (October), the density of *O. oratoria* in the Bohai Sea was higher in 2009 than from 2013 to 2014, and it increased from 2016 to 2017 and declined again in 2018. The density of *O. oratoria* was higher in the western Bohai Sea and lower in the eastern Bohai Sea than in other areas in autumn from 2009 to 2018. In winter (January), the density of *O. oratoria* was low in the Bohai Sea from 2015 to 2017.

Comparing the density and spatial distribution of *O. oratoria* in different seasons from 2016 to 2017, we found that the density of *O. oratoria* was the highest in summer (August), followed by in autumn (October) and spring (May), and the lowest in winter

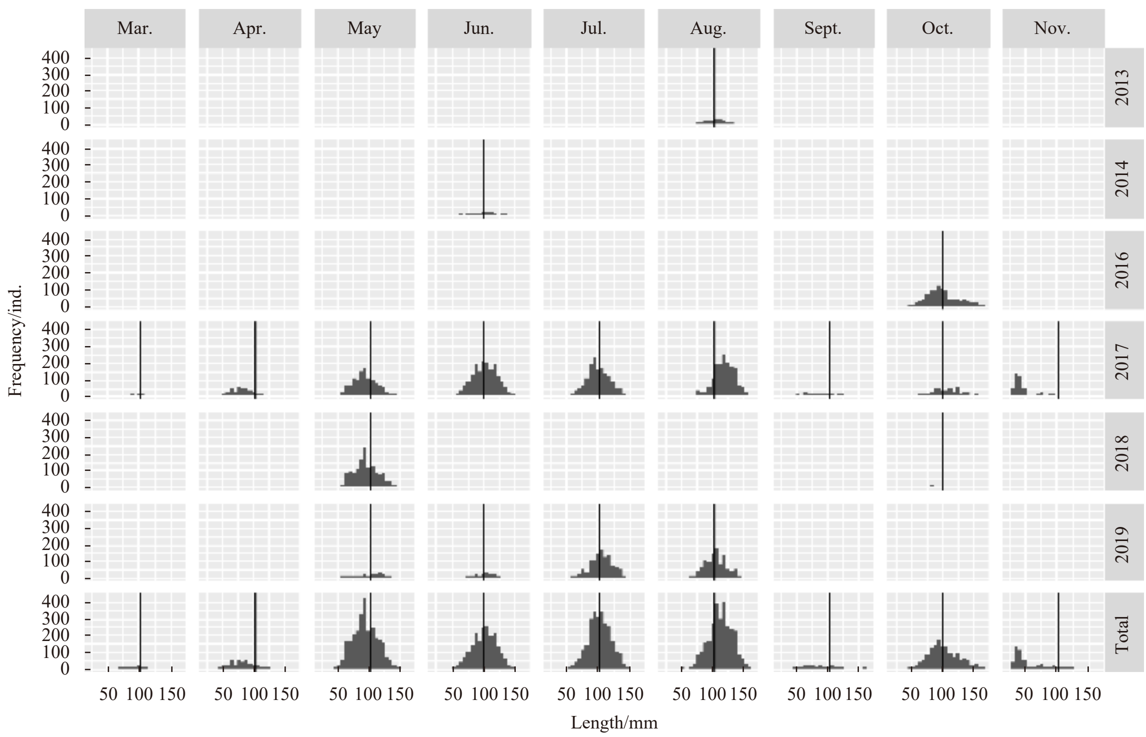

Fig. 6. Body length of *Oratosquilla oratoria* in different months from 2013 to 2019 in the Bohai Sea.

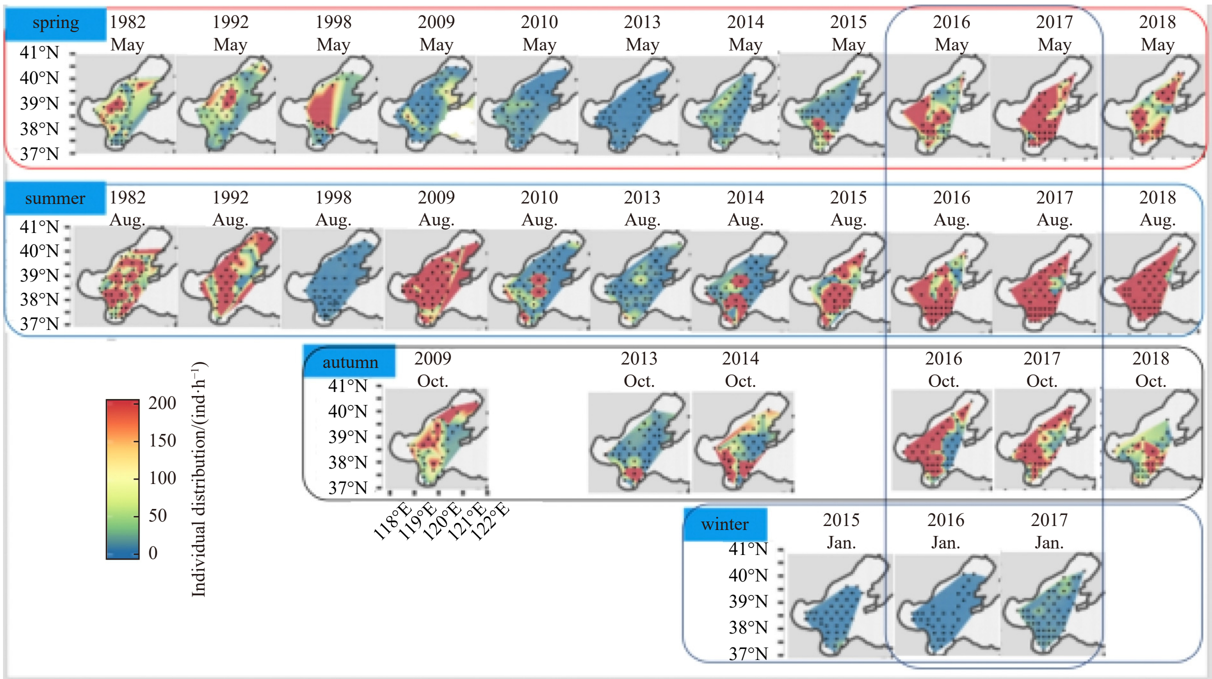

Fig. 7. Spatial distribution of *Oratosquilla oratoria* in the Bohai Sea from 1982 to 2018.

(January). In general, the density of *O. oratoria* in the western Bohai Sea was higher than that in the eastern Bohai Sea.

4 Discussion

The fishery resources of the Bohai Sea have declined sharply over the past half century due to overfishing, environmental pollution and other factors (Jin, 2004; Xu et al., 2011; Lin et al., 2016). According to the results of a long-term survey in May, the relative resource density of fish in the Bohai Sea declined from 186 kg/h in 1959 to approximately 80 kg/h in 1982 and then decreased again to less than 1 kg/h in 2010 (Shan et al., 2012). The biomass densities of most economic crustacean species also showed a sharp declining trend. According to the bottom trawling survey in Laizhou Bay of the Bohai Sea, the relative resource density of the Chinese shrimp *Fenneropenaeus chinensis* decreased from 0.24 kg/h in May 1982 to 0 kg (not caught) in May 2013 and from 0.42 kg/h in August 1982 to 0.07 kg/h in August 2013 (Wu et al., 2016a). At the same time, the relative resource density of the swimming crab *Portunus trituberculatus* decreased from 0.23 kg/h in May 1982 to 0 kg (not caught) in May 2013 and from 14.83 kg/h in August 1982 to 0.09 kg/h in August 2013 (Wu et al., 2016a). However, the relative resource density of *O. oratoria* in this study increased from 1.93 kg/h in May 1982 to 15.73 kg/h in May 2017 and from 5.24 kg/h in August 1982 to 26.35 kg/h in August 2018. The percentage of *O. oratoria* that serves as part of the fishery resources in the Bohai Sea showed a similar upward trend to that of the relative resource density. Many reasons could explain why the relative resource density increased and *O. oratoria* became dominant in the Bohai Sea in the past 30 years. First, *O. oratoria* can tolerate a wide range of temperatures (6–31℃) (Wang et al., 1998), considering the great changes in water temperature in different seasons in the Bohai Sea because of its shallow water (<30 m) and the impact of the continental climate. Second, *O. oratoria* has a high resistance to diseases (Wang et al., 1998) and is often referred to as a sea cockroach due to its hardiness and adaptability. Third, the Bohai Sea has widespread silty clay substrates, which provide suitable habitats for the burrowing habit of *O. oratoria*. Fourth, long-term overfishing has severely depleted the stocks of the species which competes with for food and space, e.g., the Chinese shrimp *F. chinensis* and the swimming crab *P. trituberculatus*, thereby increasing the food sources and habitats for *O. oratoria*. Fifth, compared with migratory species, *O. oratoria* is a cave-dwelling and settled species that does not need to break through the fishing nets in the Yellow Sea to return to the Bohai Sea to spawn. Finally, *O. oratoria* is an r-strategist with high reproductivity and a short life cycle (Kodama et al., 2004, 2005), which is conducive to its adaptation to drastic changes in the external environment of the Bohai Sea.

Many studies have shown that fish decrease under long-term overfishing (Hutchings, 2004; Olsen et al., 2004; Li et al., 2011; Zhang et al., 2020a, b). In addition, fish community structure becomes simplified, and the proportion of large predatory fish decreases (Myers and Worm, 2003; Jin, 2004; Shan et al., 2016). However, the phenomenon of crustaceans becoming smaller with overfishing has rarely been reported. In this study, the mean body weight of *O. oratoria* in the Bohai Sea showed a downward trend from 1982 to 2018. The main reason for this phenomenon is overfishing. According to the China Fisheries Statistics Yearbook, the total fishing effort in the Bohai Sea (including Liaoning, Hebei, Shandong and Tianjin) increased from 730 751 kW in 1982 to 2 282 687 kW in 2018. On the other hand, the mean body weight of *O. oratoria* decreased over the past 30 years, which verified that fishing intensity was too high in the Bohai Sea. In the 1980s, the body length and age composition of *O. oratoria* were studied, and four age groups (0–3 ages) of *O. oratoria* were found in the Bohai Sea (Deng et al., 1988). Deng et al., (1988) also concluded that *O. oratoria* is 3 years old when its body length is larger than 150 mm and 0–1 years old when its body length is less than 100 mm. Based on the above criteria, according to the statistical results of the body length of *O. oratoria* in the Bohai Sea from 2013 to 2019 (Fig. 5), 3-year-old individuals accounted for only 1.10% of the population, and 0-2-year-old individuals accounted for 98.90%. The body size of *O. oratoria* at first maturity was estimated to be approximately 8 cm (Kodama et al., 2004). In 2004, the Chinese Ministry of Agriculture stipulated that the minimum catch standard of *O. oratoria* should not be less than 11 cm for body size in the Bohai Sea. We believe this criterion is reasonable because most *O. oratoria* at this size have reproduced once.

China's fishing moratorium system began in 1995 and lasted only two months from July 1 to August 31 in the Bohai Sea. Since then, the fishing moratorium system has been extended and moved up intermittently. In 2017, China implemented a new fishing moratorium system, which is called "the strictest in history" (Wu et al., 2019), with a four-month fishing closure from May 1 to September 1 in the Bohai Sea. In this study, the relative resource density of *O. oratoria* in the fishing moratorium season from May to August was significantly higher than that in the other months of the fishing season in 2017 (Fig. 3). In addition, the mean body size of *O. oratoria* in the fishing moratorium season was also significantly higher than that in the fishing season (Figs 5 and 6). Because large individuals were selectively harvested during the fishing season. This also explains why the mean body weight of *O. oratoria* dropped sharply to 7.07 g in September. When the fishing started in September, large individuals were quickly caught, resulting in a sharp drop in the average body weight of the mantis oratoria population.

The sample numbers in May 2013 was 57. We think that the number of samples in May is relatively small, which may affect the accuracy of the average body weight, so the reference value in May 2013 is limited. The spawning season of *O. oratoria* in the Bohai Sea is from April to September, and its peak period is from May to July. We think that the spawning season have relationship with the monthly changes in biomass density and mean body size, because the spawning stock will lose weight after breeding. The density of *O. oratoria* in the western Bohai Sea is higher than that in the eastern Bohai Sea. This is closely related to the sea substrate, because the sediment geology in the western Bohai Sea is more suitable for the burrowing habit of *O. oratoria*. The seasonal variation of the density distribution is related to the living habits of *O. oratoria*, which breeds near the shore in spring, feeds in the deeper area in summer and autumn, and overwinters in the deep water area in winter.

The above results suggest that fishing behaviour had a great influence on the population density and body size of *O. oratoria* and that the fishing intensity was too high in the Bohai Sea. The effect of fishing moratoria on the increase in fishery resource density was significant, regardless of whether it was in the Yellow Sea (Lu et al., 2013), Bohai Sea (Hu et al., 2020), East China Sea (Xu et al., 2003; Cheng et al., 2004; Yan et al., 2006) or South China Sea (Su et al., 2019). However, all of the above studies found the same phenomenon: the density of fishery resources decreased rapidly in autumn to winter after the fishing moratorium ended, which indicated that the fishing intensity was too high in these sea areas. Therefore, we suggest further reductions in fishing effort in the China sea.

Acknowledgements

We thank all colleagues for their help in collecting the survey data. We thank Cody Szuwalski for his help in drawing the spatial distribution figure. We also thank a number of anonymous reviewers for their valuable comments.

References

Antony P J, Dhanya S, Lyla P S, et al. 2010. Ecological role of stomatopods (mantis shrimps) and potential impacts of trawling in a marine ecosystem of the southeast coast of India. Ecological Modelling, 221(21): 2604–2614, doi: 10.1016/j.ecolmodel.2010.07.017

Boenish R, Kritzer J, Kleisner K, et al. 2022. The global rise of crustacean fisheries. Frontiers in Ecology and the Environment. 20(2): 102–110, doi: 10.1002/fee. 2431

Cheng Jiahua, Lin Longshan, Ling Jianzhong, et al. 2004. Effects of summer close season and rational utilization on redlip croaker (*Larimichthys polyactis* Bleeker) resource in the East China Sea Region. Journal of Fishery Sciences of China, 11(6): 554–560

Colloca F, Cardinale M, Belluscio A, et al. 2003. Pattern of distribution and diversity of demersal assemblages in the central Mediterranean Sea. Estuarine, Coastal and Shelf Science, 56(3–4): 469–480

Deng Jingyao, Meng Tianxiang, Ren Shengmin, et al. 1988. Species composition, abundance and distribution of fishes in the Bohai Sea. Marine Fisheries Research, 9(1): 11–89

Garces L R, Stobutzki I, Alias M, et al. 2006. Spatial structure of demersal fish assemblages in South and Southeast Asia and implications for fisheries management. Fisheries Research, 78(2–3): 143–157

Hu Zhijun, Shan Xiujuan, Yang Tao, et al. 2020. Preliminary evaluation of summer fishing moratorium in the Bohai Sea. Progress in Fishery Sciences, 41(5): 13–21

Hutchings J A. 2004. The cod that got away. Nature, 428(6986): 899–900, doi: 10.1038/428899a

Jin Xianshi. 2000. The dynamics of major fishery resources in the Bohai Sea. Journal of Fishery Sciences of China, 7(4): 22–26

Jin Xianshi. 2003. Fishery biodiversity and community structure in the Yellow and Bohai Seas. In: Proceedings of the Third World Fisheries Congress: Feeding the World with Fish in the Next Millennium the Balance between Production and Environment. Quebec City, Canada: American Fisheries Society Symposium, 643–650

Jin Xianshi. 2004. Long-term changes in fish community structure in the Bohai Sea, China. Estuarine, Coastal and Shelf Science, 59(1): 163–171

Jin Xianshi, Shan Xiujuan, Li Xiansen, et al. 2013. Long-term changes in the fishery ecosystem structure of Laizhou Bay, China. Science China Earth Sciences, 56(3): 366–374, doi: 10.1007/s11430-012-4528-7

Kodama K, Shimizu T, Yamakawa T, et al. 2004. Reproductive biology of the female Japanese mantis shrimp *Oratosquilla oratoria* (Stomatopoda) in relation to changes in the seasonal pattern of larval occurrence in Tokyo Bay, Japan. Fisheries Science, 70(5): 734–745, doi: 10.1111/j.1444-2906.2004.00866.x

Kodama K, Yamakawa T, Shimizu T, et al. 2005. Age estimation of the wild population of Japanese mantis shrimp *Oratosquilla oratoria* (Crustacea: Stomatopoda) in Tokyo Bay, Japan, using lipofuscin as an age marker. Fisheries Science, 71(1): 141–150, doi: 10.1111/j.1444-2906.2005.00941.x

Li Zhonglu, Shan Xiujuan, Jin Xianshi, et al. 2011. Long-term variations in body length and age at maturity of the small yellow croaker (*Larimichthys polyactis* Bleeker, 1877) in the Bohai Sea and the Yellow Sea, China. Fisheries Research, 110(1): 67–74, doi: 10.1016/j.fishres.2011.03.013

Li Shitao, Wang Nuo, Zhang Yuanling, et al. 2013. Ecological impacts of marine reclamation in Bohai Sea from 1981 to 2011. Marine Environmental Science, 32(6): 926–929, 938

Lin Qun, Wang Jun, Yuan Wei, et al. 2016. Effects of fishing and environmental change on the ecosystem of the Bohai Sea. Journal of Fishery Sciences of China, 23(3): 619–629

Lu Zhenbo, Xu Bingqing, Li Fan, et al. 2013. Structure and distribution of fish resources in the Yellow Sea off Shandong during spring and autumn 2006. Journal of Fishery Sciences of China, 18(6): 1335–1342, doi: 10.3724/SP.J.1118.2011.01335

Lui K K Y, Ng J S S, Leung K M Y. 2007. Spatio-temporal variations in the diversity and abundance of commercially important decapoda and stomatopoda in subtropical Hong Kong waters. Estuarine, Coastal and Shelf Science, 72(4): 635–647

Myers R A, Worm B. 2003. Rapid worldwide depletion of predatory fish communities. Nature, 423(6937): 280–283

Olsen E M, Heino M, Lilly G R, et al. 2004. Maturation trends indicative of rapid evolution preceded the collapse of northern cod. Nature, 428(6986): 932–935, doi: 10.1038/nature02430

Shan Xiujuan, Jin Xianshi, Dai Fangqun, et al. 2016. Population dynamics of fish species in a marine ecosystem: a case study in the Bohai Sea, China. Marine and Coastal Fisheries, 8(1): 100–117, doi: 10.1080/19425120.2015.1114543

Shan Xiujuan, Jin Xianshi, Li Zhongyi, et al. 2012. Fish community structure and stock dynamics of main releasing fish species in the Bohai Sea. Progress in Fishery Sciences, 33(6): 1–9

Su Yingjia, Chen Guobao, Zhou Yanbo, et al. 2019. Assessment of impact of summer fishing moratorium in South China Sea during 2015–2017. South China Fisheries Science, 15(2): 20–28

Tang Qisheng, Jin Xianshi, Wang Jun, et al. 2003. Decadal-scale variations of ecosystem productivity and control mechanisms in the Bohai Sea. Fisheries Oceanography, 12(4–5): 223–233, doi: 10.1046/j.1365-2419.2003.00251.x

Tully O, Freire J, Addison J. 2003. Crustacean fisheries. Fisheries Research, 65(1–3): 1–2

Wang Bo, Zhang Xilie, Sun Pixi. 1998. On biological characters and artificial seedling rearing techniques of mantis shrimp (*Oratosquilla oratoria*). Journal of Oceanography of Huanghai & Bohai Seas, 16(2): 64–73

Wu Qiang, Guan Lisha, Li Zhongyi, et al. 2019. Decadal variations in the community status of economically important invertebrates in the Bohai Sea. Acta Oceanologica Sinica, 38(10): 60–66, doi: 10.1007/s13131-019-1488-1

Wu Qiang, Jin Xianshi, Luan Qingshan, et al. 2016a. Analysis on the reproduction of *Fenneropenaeus chinensis* and *Portunus trituberculatus* based on their food sources and predators in the Laizhou Bay of China. Progress in Fishery Sciences, 37(2): 1–9

Wu Qiang, Wang Jun, Zhang Bo, et al. 2016b. Monthly variation in crustacean assemblage (Decapod and Stomatopod) and its relationships with environmental variables in Laizhou Bay, China. Journal of Ocean University of China, 15(2): 370–378, doi: 10.1007/s11802-016-2714-5

Wu Jiaying, Xue Ying, Liu Xiaoxiao, et al. 2017. Long-term trends in the mean trophic level of marine fisheries in the Yellow Sea and Bohai Sea. Periodical of Ocean University of China, 47(11): 53–60

Xu Hanxiang, Liu Zifan, Zhou Yongdong. 2003. Variation of *Trichiurus haumela* productivity and recruitment in the East China Sea. Journal of Fisheries of China, 27(4): 322–327

Xu Sisi, Song Jinming, Li Xuegang, et al. 2011. Modeling of fishing effects on fishery resources and ecosystems of the Bohai Sea. Resources Science, 33(6): 1153–1162

Yan Liping, Ling Jianzhong, Li Jiansheng, et al. 2006. Simulative analysis on results of summer closed fishing in the East China Sea with Ricker population dynamic pool model. Journal of Fishery Sciences of China, 13(1): 85–91

Zhang Kui, Cai Yancong, Liao Baochao, et al. 2020a. Population dynamics of threadfin porgy *Evynnis cardinalis*, an endangered species on the IUCN red list in the Beibu Gulf, South China Sea. Journal of Fish Biology, 97(2): 479–489, doi: 10.1111/jfb.14398

Zhang Kui, Guo Jianzhong, Xu Youwei, et al. 2020b. Long-term variations in fish community structure under multiple stressors in a semi-closed marine ecosystem in the South China Sea. Science of the Total Environment, 745: 140892, doi: 10.1016/j.scitotenv.2020.140892