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Growth, mortality parameters and exploitation of the swimming crab *Portunus trituberculatus* (Miers, 1876) in the East China Sea

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ABSTRACT

Based on the samples from bottom trawls collected during March to October 2020 in the East China Sea, growth parameters, mortality rate and recruitment pattern of the swimming crab, *Portunus trituberculatus* (Miers, 1876), were estimated using FiSAT II software. Parameters of the von Bertalanffy equation obtained by ELEFAN I for males and males respectively were: growth coefficient (k) -0.99 and 1.01, theoretical maximum carapace width (L_∞) - 22.58 and 21.53 cm and theoretical age at length 0 (t_0) -0.1738 and -0.15785. Mortality parameters estimated by the length onverted catch curve analysis for males and females were: total mortality (Z) -4.26 and 4.65, natural mortality (M) -1.643 and 1.784 and fishing mortality (F) -2.617 and 2.866, for females and males, respectively. The stock recruitment showed a bimodal pattern, in which the main peak was from July to October and the second peak in February and March. The exploitation rates arrived at were 0.61 and 0.62 for females and males respectively, while the exploitation maximum (E_{max}) obtained were 0.63 and 0.61 in females and males respectively. The results showed that, female swimming crabs in the East China Sea grow faster and reach larger carapace width than males and the current exploitation rate is very high and close to the value for maximum yield, indicating overfishing.

Keywords: Biological parameters, East China Sea, Growth, Mortality, *Portunus trituberculatus*

Introduction

The swimming crab *Portunus trituberculatus* (Miers, 1876), belonging to the family Portunidae is distributed in coastal waters in the Indo-West Pacific (Carpenter and Niem, 1998). It is one of the most important target species in marine fisheries in China. In 2019, a total of 458,380 t were caught, accounting for 23.90% of the marine crustacean catch and 4.58% of total marine catch (Zhang, 2020). It is a delicious seafood with high nutritious and economic value and an important species for aquaculture. In the East China Sea, the habitat of many aquatic organisms in the continental shelf waters has been destroyed and the fishery resources are on constant decline due to excessive fishing intensity and persistent pollution (Zhang *et al.*, 2007). It feeds on benthic animals and is also preyed by fishes (Liu *et al.*, 2020). Studies have shown that the wild biomass of the crab has been declining (Yang *et al.*, 2009) and artificial breeding and stock enhancement has become an important guarantee for maintaining the resources of this species or even the ecosystem's stability (Bell *et al.*, 2006; Bartley and Bell, 2008). Studies are needed to understand the inherent causes of stock fluctuations and to formulate strategies for the reasonable exploitation of the swimming crab.

From fishery surveys and studies, good time series data of body length and weight of target species are available. This type of data could be used in the studies on growth, mortality, exploitation and population structure of target species which are more important for species with limited information about age structure (Sparre and Venema, 1998). Data on length frequency were also used to fit and calculate biological parameters, age structure, population size, mortality (Kohler *et al.*, 1995) and population evaluation (Sparre and Venema, 1998; Blackwell *et al.*, 2000; Salarpouri *et al.*, 2018) of aquatic organisms. Growth, mortality and exploitation rate are important reference for stock assessment and fishery management, and swimming crabs in the East China Sea are in urgent need of these. In this study, we determined the asymptotic carapace width, growth and mortality coefficients of *P. trituberculatus* and further discuss its fishery and exploitation status based on the carapace width and body weight data from trawl surveys during 2020 in the East China Sea. The results could provide information on the status of exploitation of *P. trituberculatus* and promote fishery management at a sustainable level in the East China Sea.

Materials and methods

Sampling and measurements

Samples of *P. trituberculatus* were collected randomly every month from trawl catches from the East China Sea (Fig. 1) during March to October 2020. Live crabs or fresh samples were transported to the laboratory for biological measurements. Males and females were segregated and carapace width and body weight were measured sex-wise to an accuracy of 0.01 mm and 0.1 g, respectively.

Data analysis

The carapace width-body weight relationship, growth parameters, mortality rate and yield per unit recruit of female and male crabs were calculated separately by FiSAT II software (Gayanilo *et al*., 2005).

Carapace width-body weight relationship

The relationship between carapace width and body weight of female and male swimming crabs were fitted separately by power function model:

$$W = a \times L^b$$

where W is body weight in g, L is carapace width in cm and a and b are parameters in the relationship between carapace width and body weight.

Growth parameters

The growth of female and male crabs was described by the von Bertalanffy's growth equation (von Bertalanffy, 1938; Zhan, 1995) as:

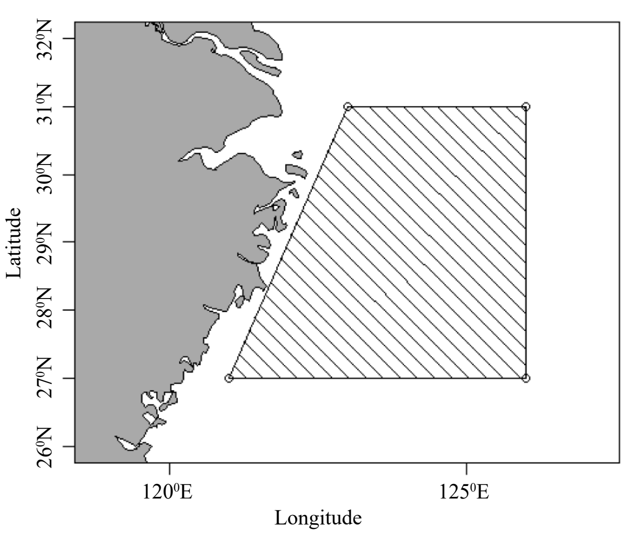

Fig. 1. Sampling area in the East China Sea

$$L_t = L_\infty \{1 - e^{\wedge}[-K\,(t-t_0)]\}$$

where L_t is the carapace width at age t; L_∞ is the asymptotic carapace width; t_0 is the theoretical age when the carapace width is zero, usually a negative number; K is the relative velocity of the growth curve approaching the asymptotic value.

The growth parameters L_∞ and K were estimated by the ELEFAN (Electronic Length Frequency Analysis) method (Pauly and David, 1981). The optimum values were selected by R_n (Pauly, 1980):

$$R_n = (10\text{ESP} / \text{ASP}) / 10$$

where ASP (available sum of peaks) and ESP (explained sum of peaks) are the sum of maximum scores of available peaks and the sum of scores of used peaks, respectively.

The estimation of t_0 was estimated by Pauly's empirical formula (Pauly and David, 1981):

$$\ln(-t_0) = -0.3922 - 0.2752 \times \ln L_\infty - 1.038 \times \ln K$$

Mortality rate and exploitation rate

The total mortality rate was estimated by the length converted catch curve method in FiSAT II software. Natural mortality rate was estimated by Pauly, 1980.

Stock recruitment model

The stock recruitment model was estimated by FiSAT II software based on carapace width data and the parameters L_∞ and K were input to reconstruct the annual stock recruitment phase of the swimming crab (Gao *et al.*, 2014).

Relative yield-per-recruit

The yield per unit recruit of the swimming crab was analysed by the relative yield-per-recruit (Y'/R) model using Knife-edge selection in the Beverton-Holt module of FiSAT II. The exploitation rate (E) in FiSAT II software includes the following levels: E_{max} is the exploitation rate to produce maximum yield; E_{10} is the exploitation rate when the marginal increase of Y'/R is reduced by 10% and E_{50} is the value of E at which the stock has been reduced to 50% of its unexploited biomass (Pauly, 1980).

Results

Carapace width and body weight

Carapace width and body weight of *P. trituberculatus* from the East China Sea ranged from 3.0 to 21.4 cm and 3.0 to 548.6 g respectively and dominant groups of carapace width were 8.0 to 15.0 cm. For females, carapace width and body weight ranged from 5.7-20.8 cm and 5.55-452.80 g respectively and dominant groups of carapace width were 9.0-15.0 cm. For males carapace width and body weight ranged from 3.0-21.4 cm and 3.0-548.6 g respectively and dominant groups of carapace width were 8-14 cm. The average carapace width of females (12.6±0.1 cm) was larger than that of males (12.2±0.1 cm) (f = 7.243, p<0 .01); but there was no significant difference (f = 0.946, p>0.05) between the average body weights of females (125.77±3.26 g) and males (121.00±3.66 g). The distribution of carapace width of males and females both showed bimodal pattern and peak values of females were larger than those of males (Fig. 2).

The growth curves of females and males were also different. Results of the power function model fit showed that the relationship between carapace width and body weight was $W = 0.0533 \times L^{3.0147}$ for males and $W = 0.0597 \times L^{2.9594}$ for females (Fig. 3). The exponent of the power function was smaller in females than in males (f = 18.509, p<0.001), while the coefficient of the power function was bigger in females than in males (f = 23.451, p<0.001).

Sex ratio

The ratio of female and male individuals in the samples of *P. trituberculatus* in the East China Sea was close to 1: 1 ($\chi^2 = 0.252$, p = 0.615), in which females and males made up 50.85 and 49.15% of the total individuals respectively. The proportion of females and males fluctuated in different months. For females, the proportion of individuals was the highest at the end of March (70.89%) and the lowest in August (31.45%) (Fig. 4).

Growth parameters and growth equation

The asymptotic carapace widths of females and males of the crabs were 22.58 and 21.53 cm, respectively (Fig. 5). The value of growth coefficient of carapace width was lower in females (0.99) than in males (1.1). The value of t_0 of carapace width was -0.1579 in males, which was higher than (-0.1738) females.

The growth equation of carapace width of the swimming crab was $L_t = 21.53 \times (1\text{-}e^{-1.1(t + 0.1579)})$ in males and $L_t = 22.58 \times (1\text{-}e^{-0.99(t + 0.1738)})$ in females. The growth equation of body weight of the swimming crab was $W_t = 0.52 \times (1\text{-}e^{-1.1(t + 0.1579)})$ ^3.0147 in males and $W_t = 0.51 \times (1\text{-}e^{-0.99(t + 0.1738)})$ ^2.9594 in females.

Mortality and exploitation rate

Total mortality, natural mortality and fishing mortality of males were Z = 4.65, M = 1.784 and F = 2.866,

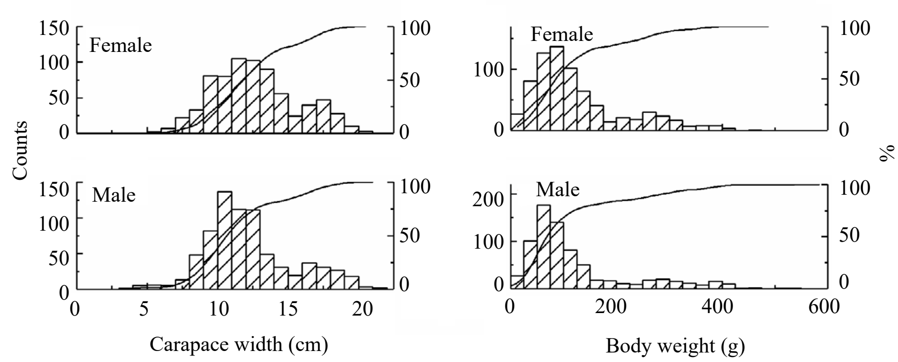

Fig. 2. Frequency distribution of carapace width and body weight of female and male *P. trituberculatus* in the East China Sea

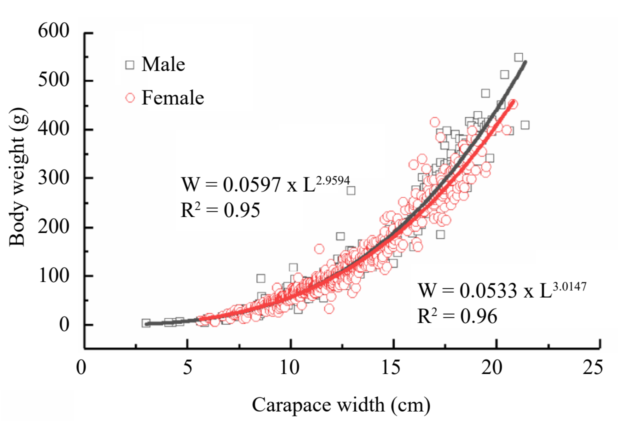

Fig. 3. Carapace width-body weight relationship of *P. trituberculatus* in the East China Sea

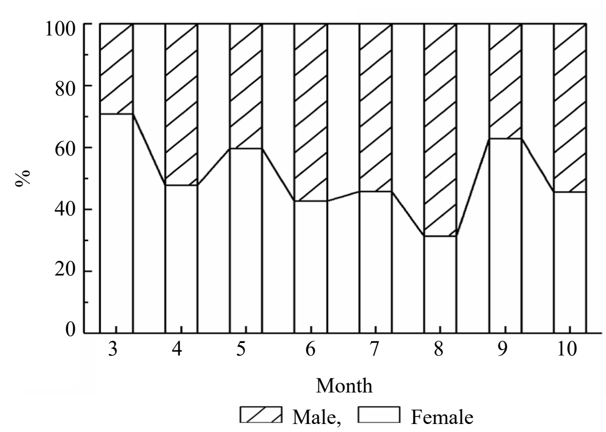

Fig. 4. Variation in the proportion of individuals of different sexes of *P. trituberculatus* in the East China Sea

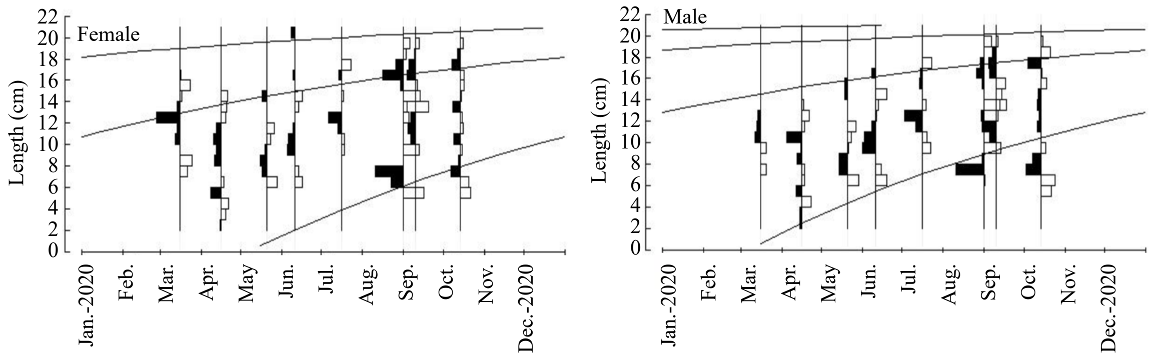

Fig. 5. Growth curve of female and male *P. trituberculatus* in the East China Sea

respectively; while the corresponding parameters for females were lower (Z = 4.26, M = 1.643 and F = 2.617, respectively). Females were exploited at a lower rate (0.61) than males (0.62).

Stock recruitment pattern

The stock recruitment patterns of females and males of *P. trituberculatus* were both mainly bimodal. The main recruiting phase was from July to October, and there was a lower peak from February to March (Fig. 6).

Mean selection carapace width

The probability of capture, *i.e.,* the mean selection carapace width (L_c), was 8.77 cm for males and 9.38 cm for females (Fig. 7).

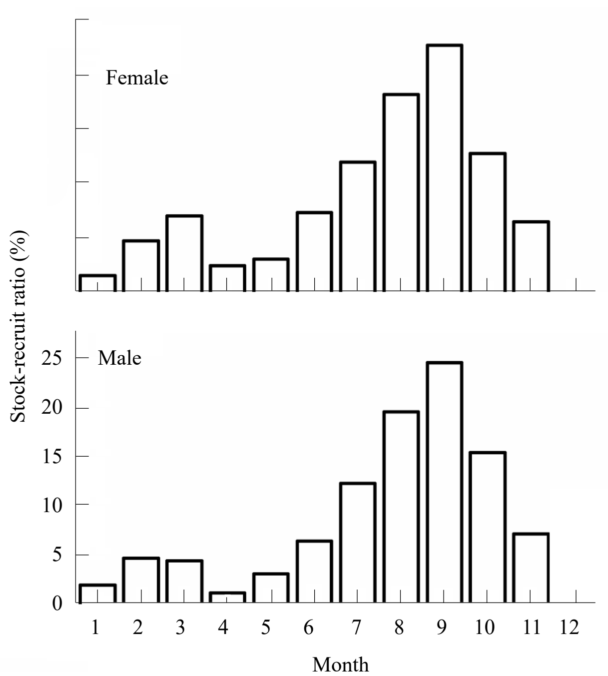

Fig. 6. Recruitment patterns of female and male *P. trituberculatus* in the East China Sea

Relative yield-per-recruit

The current exploitation level of *P. trituberculatus* could be illustrated by two-dimensional presentation of the relative yield-per-recruit (Y'/R) and the exploitation rate (*E*). The exploitation rate when the marginal increase of Y'/R is reduced by 10% (E_{10}) was 0.504 in females and 0.514 in males. The value of *E* at which the swimming crab stock has been reduced to 50% of its unexploited biomass (E_{50}) was 0.337 in females and 0.335 in males. The exploitation rate to produce maximum yield (E_{max}) was 0.63 and 0.61 in females and males, respectively (Fig. 8).

Discussion

In the growth process of aquatic organisms, individuals of different sexes of the same species often have differences in morphology and growth characteristics, mainly due to the differences in gene expression (Toguyeni *et al*., 2002; Deng *et al*., 2014), reproductive strategy (Wang*et al.*, 2006) and feeding habits (Li *et al.*, 1997). Females often grow faster than males in fishes such as the Nile tilapia (*Oreochromis niloticus*) (Ma*et al.,* 2015), the spotted scat (*Scatophagus argus*) (Wu *et al.*, 2013) and the turbot (*Scophthalmus maximus*) (Wang *et al.*, 2014). Crustaceans also have sex dimorphism in morphological and growth characteristics, but the scenarios are more complicated than in fishes. The difference of growth velocity between males and females in shrimps and crabs depends on species. Females of some species such as *Exopalaemon modestus*, *Palaemon adspersus* and *Parapenaeopsis stylifera* grow faster than males (Berglund, 1981; Oh *et al.,* 2002; Safaie, 2017), while other species such as *Holthuispenaeopsis atlantica* (Okpei *et al.,* 2020) do the opposite. The value of *a* in the power function of body weight and length relationship could be used as one of the indicators of relative fatness (Yatsu *et al.,* 1997). This study showed that the *a* value of female swimming crab (*P. trituberculatus*) was higher than that of males, indicating that the fatness of females was higher than males. The

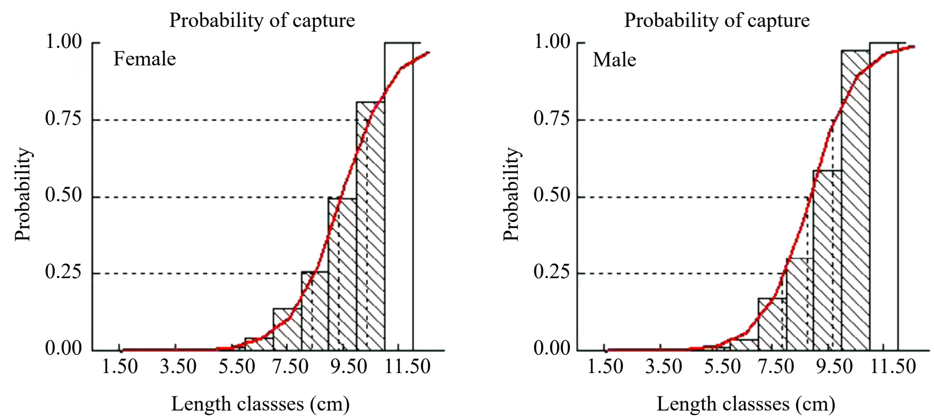

Fig. 7. Mean selected carapace width from the proportional retention of length-converted catch curve of female and male *P. trituberculatus* in the East China Sea

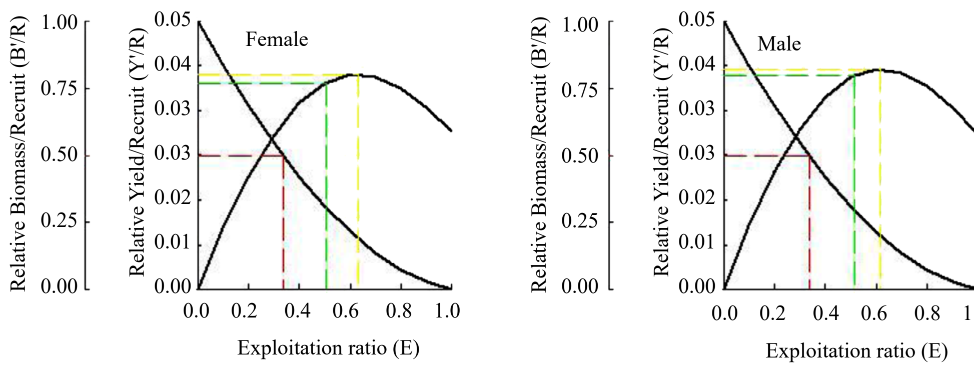

Fig. 8. 2D presentation of the relative yield per recruit and the relative biomass per recruit of female (L_c = 9.38 cm) and male (L_c = 8.77 cm) (*P. trituberculatus*) in the East China Sea

values of growth factor *b* in the body weight-length power function were close to 3, indicating a nearly isokinetic growth of the swimming crabs. The difference in growth factor *b* showed that the growth pattern was different. The *b* value of females was lower than that of males, which means that the growth velocity of females was lower than that of males. The results of growth coefficient of *P. trituberculatus* were consistent with the results obtained by growth factors, and the growth coefficient of males was higher than that of females. This might be related to the difference of reproductive strategies between males and females. During the development of the ovary, females spend more energy and material supply on reproductive activities and also store some energy appropriately, so their fatness coefficient were high while the growth in the body length slow down. This result of our study was consistent with that on the relationship between carapace width and body weight of *P. trituberculatus* in coastal waters of Zhejiang Province in 2015-2016 (Wang *et al.,* 2018), but was different from those of swimming crabs in the northern East China Sea and the southern Yellow Sea in 2006 (Yuan *et al.,* 2016), the Laizhou Bay of Bohai Sea in 2012 (Yang *et al.*, 2017), and the northern East China Sea in 2012-2013 (Zhang *et al.,* 2015) (Table 1). It was found that the fatness indicator *a* and growth factor *b* of swimming crabs in the East China Sea in this study were both higher than those of the Laizhou Bay of Bohai Sea and in the northern East China Sea and southern Yellow Sea. This could be related to the differences in food supply and hydrological conditions in different seas. In the same area, the fatness indicator *a* and growth factor *b* of swimming crabs gradually increased over time, which might be related to fishery protection measures such as enhancement and release in recent years.

Since the growth and development of crabs was in stages, the growth velocity was in a dynamic change. The results showed that the carapace width-body weight curve of the swimming crab was not consistent with different carapace width groups. The growth rate of juveniles after hatching was the fastest and then it gradually decreased (Song *et al.,* 1989). Wang *et al.* (2018) found

Table 1. Carapace width- body weight relationships of female and male *P. trituberculatus* in different areas of China Sea

Area	Year	a	b	References
Northern East China Sea and southern Yellow Sea	2006	♀ 0.003 ♂ 0.004	♀ 2.7012 ♂ 2.5992	Yuan *et al*. (2016)
Laizhou Bay of Bohai Sea	2012	♀ 5.81×10^{-5} ♂ 7.75×10^{-5}	♀ 2.955 ♂ 2.899	Yang *et al*. (2017)
Northern East China Sea	2012-2013	♀ 4.639×10^{-4} ♂ 5.854×10^{-4}	♀ 2.551 ♂ 2.504	Zhang *et al*. (2015)
Coastal waters of Zhejiang Province, East China Sea	2015-2016	♀ 0.0704 ♂ 0.05923	♀ 2.8772 ♂ 2.9421	Wang *et al*. (2018)
East China Sea	2020	♀ 7×10^{-5} ♂ 5×10^{-5}	♀ 2.9594 ♂ 3.0147	This study

Note: ♀ for female and ♂ for male.

that there were seasonal differences in the growth rate of the swimming crab in the coastal waters of Zhejiang Province in the East China Sea. This could be related to different growth requirements at different stages of the life history of the swimming crab. The peak periods of spawning, feeding and overwintering groups of the swimming crab were in different seasons, while the life activities of these groups had different focuses. This may be related to the effect of temperature in different seasons on its growth. Tettelbach and Rhodes (1981) suggested that many environmental factors affect the adaptability of organisms, especially temperature. Crustaceans are typical poikilotherms and unable to regulate body temperature and their physiological functions are affected by the change of ambient temperature (Wang *et al.,* 2010). At certain temperature, the development rate and growth rate of crustacean larvae increase with the increase of temperature (Neuparth *et al.,* 2002). At the same time, temperature was an important factor affecting the maturation of crustaceans (Carmona-Osalde *et al.,* 2004). Females and males of the swimming crab also had different life cycles due to different reproductive habits and life history characteristics. Results of this study showed that the asymptotic carapace width of female swimming crabs was longer than that of males.

Generally, E_{10} and E_{max} are used as biological standards for fishery resources assessment in a given sea area, while sometimes 0.5 is taken as the optimal rate of exploitation (Gulland and Oerema, 1973). It is often presumed that the fishery resources would be sustainable if the exploitation rates were within the optimal limit (Mehanna, 2007). However, the selection of different criteria E_{10} and E_{max} would affect the degree of exploitation in a region, which would eventually be reflected in the formulation of related policies. Studies had shown that E_{max} as the biological reference standard might lead to overly optimistic assessments, while E_{10} and 0.5 standards could balance the current catches and reasonable utilisation (Gulland and Oerema, 1973; Cook, 1998). The biological reference points E_{10} or 0.5 had been adopted in other species such as *Penaeus indicus* (Saputra *et al.,* 2019) and *Penaeus merguensis* (Saputra *et al.,* 2018). The exploitation rates of female and male swimming crabs calculated in this study were 0.61and 0.62, respectively, which were higher than the optimal rates of E_{10} and 0.5, but close to the E_{max}. If the E_{max} was set as the biological reference point, the exploitation rate of *P. trituberculatus* in the East China Sea would fall in the acceptable range. However, taking the current resource status of the swimming crab in the East China Sea into account, the E_{10} and 0.5 were more suitable as reference standards, that is, the resource has been in overfishing. Statistics show that the swimming crab was facing great fishing pressure in the East China Sea. The fishing effort was still too large even though the total tonnage of fishing vessels in the East China Sea had generally been in a downward trend since the year 2016. Overfishing pressure resulted in an average decrease by 4.8% per year in the annual catch of the swimming crab. The swimming crab resource is overfished in the northern East China Sea and southern Yellow Sea (Yuan *et al.,* 2016), and other China seas such as the Bohai Sea (Yang *et al.*, 2017). Some researchers believed that the swimming crab resource under current fishing pressure could only be maintained by conservation measures such as enhancement and release in the East China Sea (Xu *et al.,* 2018; Xu *et al.,* 2019). Results of the Generalized Additive Model (GAM) showed that the catch of the swimming crab in the northern East China Sea mainly depend on the number of released larvae of this species (Wang *et al.,* 2016). The differences of growth and mortality characteristics between released groups and natural groups of the swimming crab (*P. trituberculatus*) need to be further studied.

In summary, carapace width and body weight distributions of males and females of the swimming crab (*P. trituberculatus*) in the East China Sea were unimodal. There were significant differences in the relationship between the carapace width-body weight of female and male swimming crabs; the value of the exponent of the power function in females was smaller than that of males, while the value of the coefficient of the power function in females was greater than that of males, indicating that the growth pattern was different by sex. The sex ratio depended on season, and the proportion of females was the highest in summer and the lowest in spring. Females grew faster with higher asymptotic carapace width than males. The recruitment models of females and males of the swimming crab were both bimodal, and the main and the secondary recruitment seasons were in summer and spring, respectively. Total mortality, natural mortality and fishing mortality of males were all higher than females. Fishing mortality was higher than natural mortality both in females and males, indicating that fishing was the main factor for the population recession of the swimming crab. The exploitation rates of the swimming crab were 0.61 in females and 0.62 in males, both were far greater than the optimal and close to the exploitation rates at the maximum catch. *P. trituberculatus* is one of the species with short life span and the fishing pressure on this species had exceeded the optimum range, *i.e*. the swimming crab is being overfished in the East China Sea. Hence, management policies should be formulated in a manner to reduce fishing intensity during the peak period of reproduction so as to ensure sustainable utilisation of the resource.

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