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Population Dynamics of the Swimming Crab *Portunus trituberculatus* (Miers, 1876) (Brachyura, Portunidae) from the West Sea of Korea

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ABSTRACT

A comprehensive understanding of growth parameters, mortality rates and exploitation factors are essential to develop efficient fisheries management and conservation measures. In this study acquired monthly catch data of *Portunus trituberculatus* from commercial trap surveys between January to December 2009 from the West Sea of Korea. For estimation of growth and mortality parameters, monthly carapace width-frequency data were analysed by ELEFAN I. Regressions of body weight versus carapace width indicated isometric growth (exponents very close to 3.0). Parameters of growth were estimated using the modified von Bertalanffy Growth Function (VBGF) model. Males grew faster and reached a larger size at equivalent age than females ($K = 0.94$ year^{-1} and $CW_\infty = 22.40$ cm for males and $K = 0.84$ year^{-1} and $CW_\infty = 22.20$ cm for females). Maximum life span was estimated at 2.89 and 2.49 years for females and males, respectively. Estimated values of total, natural and fishing mortality were greater in males. The exploitation rate (E) corresponding to 50% of the unexploited stock was 0.35 for females and 0.39 for males. Comparison of results from this study with another study conducted 12 years ago revealed considerable differences in the population dynamic. The present study found evidence of a local *P. trituberculatus* population under stress from heavy fishing pressure. There is an urgent need for further research to assess the rebound capacity of this species in response to ongoing exploitation pressure.

Key words: *Portunus trituberculatus*, population structure, growth, mortality, recruitment, body size, sea surface temperature (SST), West Sea of Korea

INTRODUCTION

The swimming crab *Portunus trituberculatus* (Miers, 1876) is widely distributed on sandy and muddy substrates in the coastal waters of Korea, Japan and China which also the focus of a very valuable commercial portunid crab fishery industry worldwide (Secor *et al.*, 2002). Growth, mortality and life history parameters of this species have been widely studied (Yeon, 1999; Yeon *et al.*, 1998; Xue *et al.*, 1997). However, to date no study has examined the population dynamic of each sex separately. Von Bertalanffy Growth Functions (VBGF) are generally fitted to estimate of growth parameters, mortality and the mean length at estimated age of a year class (Roa and Erns, 1996; Tuck *et al.*, 1997; Oh and Hartnoll, 2000; Oh *et al.*, 1999).

A comprehensive understanding of efficient fisheries management practices requires biological information on the life history of target and non-target stocks for the assessment of a species' growth and mortality rates, recruitment, age-at-maturity and overall life-span (Hoenig and Gruber, 1990; Anonymous, 1999). The effects of fishing or environmental variability on commercial stocks may not be apparent for decades because of the time scales over which targeted populations react to life history pressures (Jennifer and Richard, 2011).

Furthermore, knowledge of natural mortality rates is also important for understanding ecological processes and for rational management of exploited populations. However, estimation of natural mortality are often acquired using indirect methods such as correlation of M with other life history parameters including growth rate, age at sexual maturity, environmental temperature and predation rates and body size (Gislason *et al.*, 2010).

The study area (West Sea of Korea, Yellow Sea) is characterized by good moderate fine sand and silty sediments and is relatively shallow. These physical characteristics have been known to provide highly suitable habitats for *P. trituberculatus* and thus serve as an ideal nursery ground (Engel and Thayer, 1998; Guillory *et al.*, 2001). In this study, we describe the sex-specific size structure, growth and mortality rates, exploitation rate, recruitment, carapace width at capture and yield-per-recruit in order to gain an insight into population dynamics from a sustainable management perspective.

MATERIALS AND METHODS

Data collection: Specimens of *P. trituberculatus* were collected from West Sea of Korea, Yellow Sea (36°00' to 37°00'N, 125°30 to 126°30' E) (Fig. 1) from January to December 2009. Sex was determined by the shape of the abdomen. Carapace Width (CW), the distance between the tips of the longest lateral spines was measured to the nearest 0.8 cm (converted of 80 mm) using a digital vernier caliper (Mitutoyo model 500-161U) and total weight was recorded with an electronic balance to 0.001 g accuracy. Crabs were captured using crab gill nets and crab traps. The crab gill nets used ranged from 200-400 m long and 6-8 m deep with sections of 2 inch square meshes. The traps (diameter = 70 cm and height = 25 cm) were baited with 150-250 g of fresh fish. Sampling was undertaken once every 2-4 weeks depending on the weather. Sea Surface Temperature (SST) was recorded on each sampling day using a YSI sensor. During the study period, SST varied between 2 and 22.76°C (Mean±SD = 12.95±7.57°C) and was higher in summer (average of 22.76°C in June and 19.89°C in July) and lower in winter (average of 1.9°C in December and 2.1°C in January).

Data analysis

Growth parameters and longevity: To establish the carapace width-weight relationship, the commonly used relationship $W = aCW^b$ was applied (Ricker, 1975; Quinn and Deriso, 1999), where W is the weight (g), where CW is the Carapace Width (cm), a is the intercept (condition factor) and b is the slope (growth coefficient, i.e., fish relative growth rate). The parameter a and b were estimated by least squares linear regression on log-log transformed data: $\log_{10} W = \log_{10} a + b \log_{10} CW$. The coefficient of determination (r^2) was used as an indicator of the quality of the linear regression.

Carapace width-frequency distributions were constructed, using 0.8 cm width intervals of carapace width. The VBGF model was applied to all data sets to acquire the growth trajectory of crabs using the Electronic Length-frequency Analysis I (ELEFAN I) routine of the FiSAT II program package (Gayanilo *et al.*, 2005):

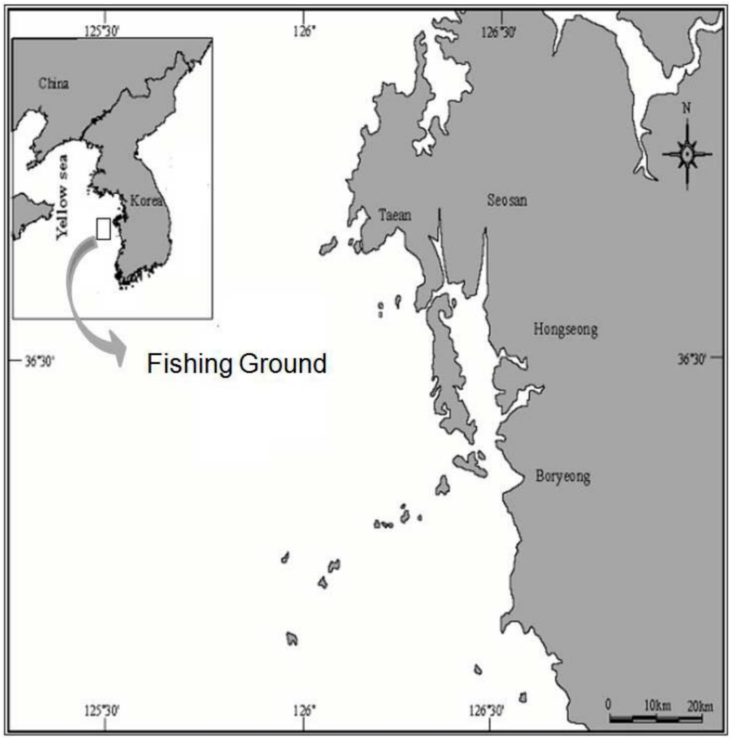

Fig. 1: Location of the study site on the West Sea of Korea, at approximately 36°00' to 37°00'N and 125°30 to 126°30' E (arrow)

$$CW_t = CW_\infty(1 - \exp^{(-K(t-t_0))}) \tag{1}$$

where, CW_t is the width at time t, CW_∞ is the asymptotic carapace width size (in cm), t_0 is the age at size zero, t is the age (years) and K is the curving parameter of the growth function.

Comparison of growth performances of *P. trituberculatus* was made using a growth performance index (φ') (Pauly and Munro, 1984):

$$\varphi' = 2\log_{10} CW_\infty + \log_{10} K \tag{2}$$

The growth performance index is preferred for growth comparison rather than comparison of CW_∞ and K individually, because these two parameters are correlated. The growth performance index is more robust than either CW_∞ or K individually as it takes into account the negative correlation between the two parameters and fulfils the requirement for a simple single parameter for comparison of growth. Also, this index allows for comparison of the growth potential of different sexes or within genus to evaluate patterns along latitudinal gradients and/or among taxonomic groups.

The theoretical life span (t_{max}) (equal to relative age because the larval period of this species is unknown, t = 0) of *P. trituberculatus* was estimated by inverse von Bertalanffy growth equation (Taylor, 1958):

$$t_{max} = \frac{[\ln CW_{95\%} - \ln(CW_{\infty} - CW_{95\%})]}{K} \quad (3)$$

where, $CW_{95\%}$ represents 95% of the maximum carapace width recorded during field sampling.

Mortality: Total mortality was estimated in ELEFAN I using two methods incorporated in FiSAT II: a linearized, length-converted catch curves (Pauly, 1983, 1984) (Eq. 4) and a Jones and van Zalinge plot (Jones and Van Zalinge, 1981) (Eq. 5):

$$\ln (N) = g\text{-}Z.t \quad (4)$$

where, N is the number of individuals, g is the regression intercept, Z is the unbiased mortality estimate and t is the estimated age (year) for each cohort (Pauly *et al*., 1995):

$$\ln (CW_{i\infty}) = g.\ \ln (CW_{\infty}\text{-}CW_i) \quad (5)$$

where, $CW_{i,\infty}$ is the cumulative catch corresponding to carapace width class i, CW_i is the lower limit of carapace width class i and g is the regression intercept.

To investigate associations between body size, mean SST and natural mortality, we followed an explorative approach where growth parameters (CW_{∞} and K) were input into two methods; The Gislason *et al*. (2010) method (Eq. 6) and the Pauly (1980) method (Eq. 7):

$$\ln (M) = 0.55\text{-}1.61 \ln (CW)+1.44 \ln (CW_{\infty})+ \ln (K) \quad (6)$$

where, CW_{∞} is the asymptotic carapace width, K is the growth coefficient and CW is the body size of carapace width:

$$\ln (M) = -0.152\text{-}0.27955 \ln (CW_{\infty})+0.6543 \ln (K)+0.463 \ln (T) \quad (7)$$

where, CW_{∞} is the asymptotic carapace width, K is the growth coefficient and T is the mean annual SST (°C).

Fishing mortality (F $year^{-1}$) was estimated by subtracting average M from average Z and for an estimate of the exploitation rate E by dividing F by average Z.

Yield-per-recruit (Y'/R) and biomass-per-recruit (B'/R).

To estimate the level of *P. trituberculatus* exploitation that would provide optimum yields, based on the Beverton and Holt (1966) model and modified by Pauly and Soriano (1986), relative yield-per-recruit and biomass-per-recruit as a function of exploitation rate (E) were determined as:

$$Y'/R = EU^{M/K}[1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{U^3}{(1+3m)}] \quad (8)$$

where, $U = 1\text{-}(CW_c/CW_{\infty})$, m = (1-E)/(M/K) = (K/Z) and E = F/Z. CW_c is the 50% retention length. CW_{∞} is the asymptotic width from the von Bertalanffy growth equation, E is the exploitation rate, M is the natural mortality, K is the growth coefficient from the von Bertalanffy growth equation and Z is the total mortality.

The exploitation rate (E_{max}) was estimated from the analysis of relative yield-per-recruit. Also, $E_{0.1,}$ the level of exploitation at which the marginal increase in yield-per-recruit reaches 10% of its value at E = 0 and E = 0.5, the exploitation level which will result in a reduction of the unexploited biomass-per-recruit.

Relative biomass-per-recruit is estimated from the relationship:

$$B'/R = (Y'/R)/F \tag{9}$$

while E_{max}, $E_{0.1}$, $E_{0.5}$ are estimated using the first derivative of this function. The two models were estimated, using the FAO-ICLARM Stock Assessment Tools (FiSAT) II (Gayanilo *et al.*, 2005).

RESULTS

Population structure: From the 10 monthly samples (January to December 2009), a total of 11,126 *P. trituberculatus* (5,437 females and 5,689 males) were collected. The monthly changes in population structure are presented in Fig. 2. Individual sizes of *P. trituberculatus* ranged from

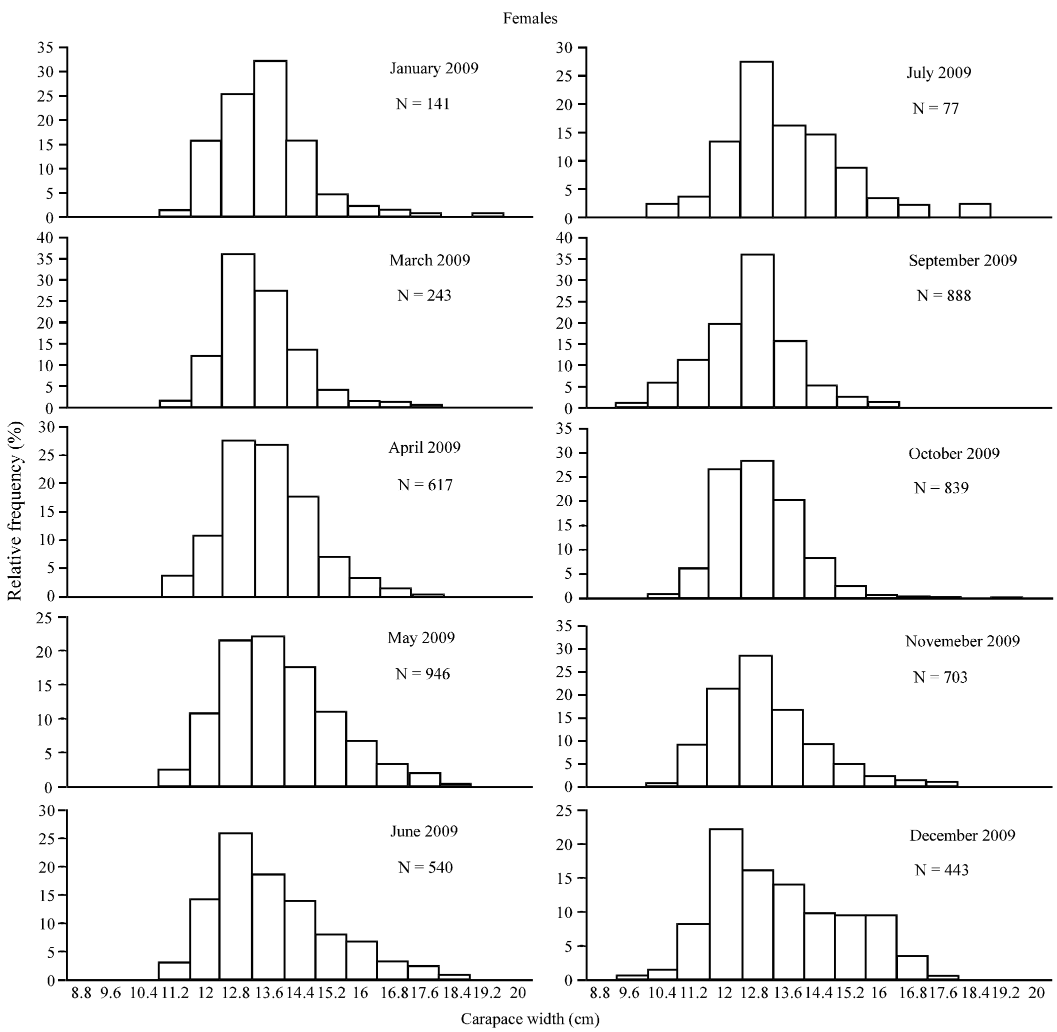

Fig. 2: Continue

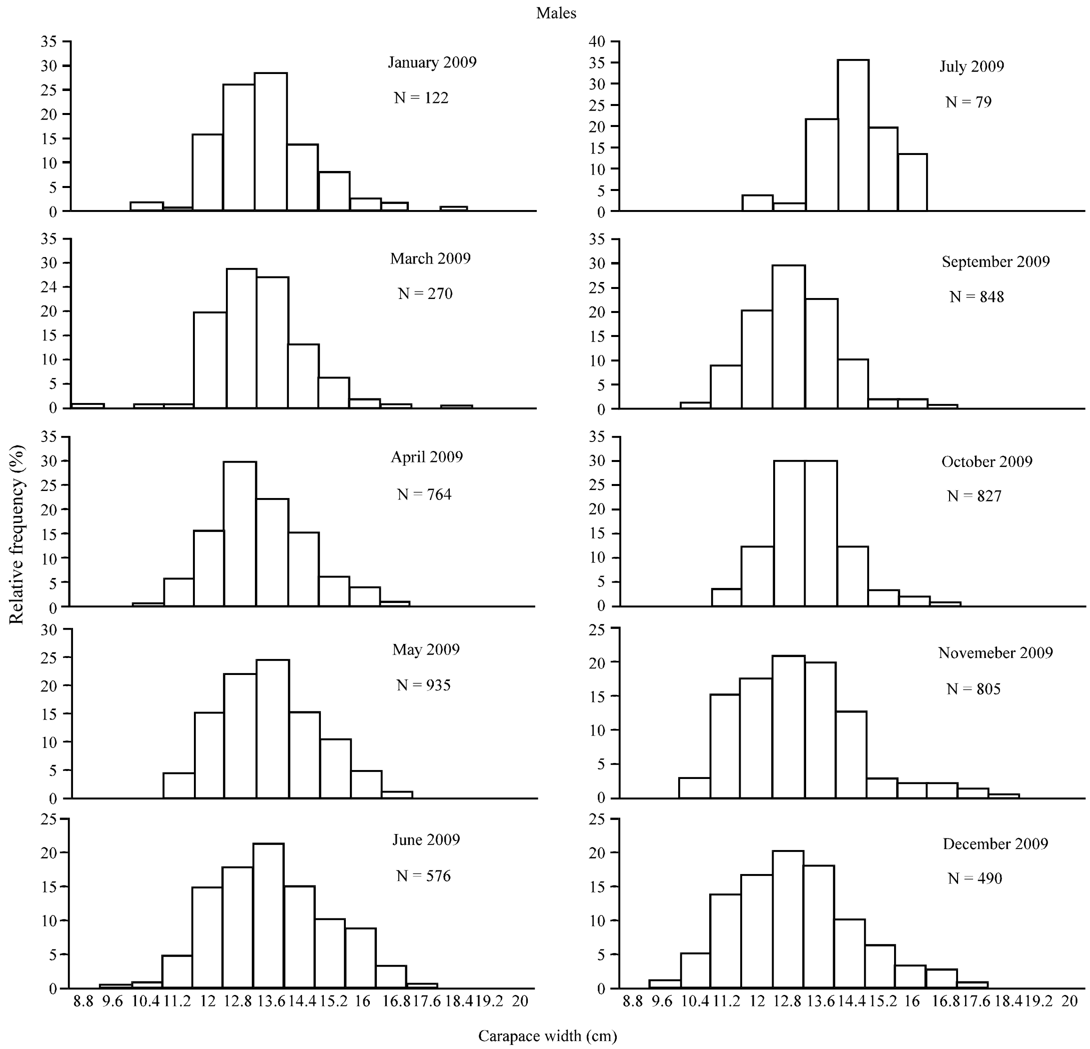

Fig. 2: Size frequency distribution of female and male *P. trituberculatus*. Monthly sampling are indicated. N, number of measured individuals.

8.8 to 20 cm. Individuals in the 12-14.4 cm size spectrum dominated the population throughout the year. While the lower size categories (8.8-10.4 cm) were consistently represented in the population, individuals in the upper size limits (18-20 cm) occurred infrequently in the samples, having the least number of individuals throughout the study.

Carapace width-weight relationship: The carapace width of individuals ranged from 4.5 to 19.5 cm and the weight from 9 to 372 g. The carapace width-weight relationship curve is presented in Fig. 3. The calculated carapace width-weight equation was logW = -0.8710+2.6562 log CW for females and logW = -0.77.7+2.5955 log CW for for males. In exponential form the equation is $W = 0.1346CW^{2.6562}$ ($R^2 = 0.996$; n = 335; p<0.01) for females and $W = 0.1684CW^{2.5966}$ ($R^2 = 0.9971$, n = 390; p<0.01) for males.

Growth parameters and longevity: The original carapace width frequencies used as input for the ELEFAN I program are shown in Fig. 4, together with the von Bertalanffy growth curves and

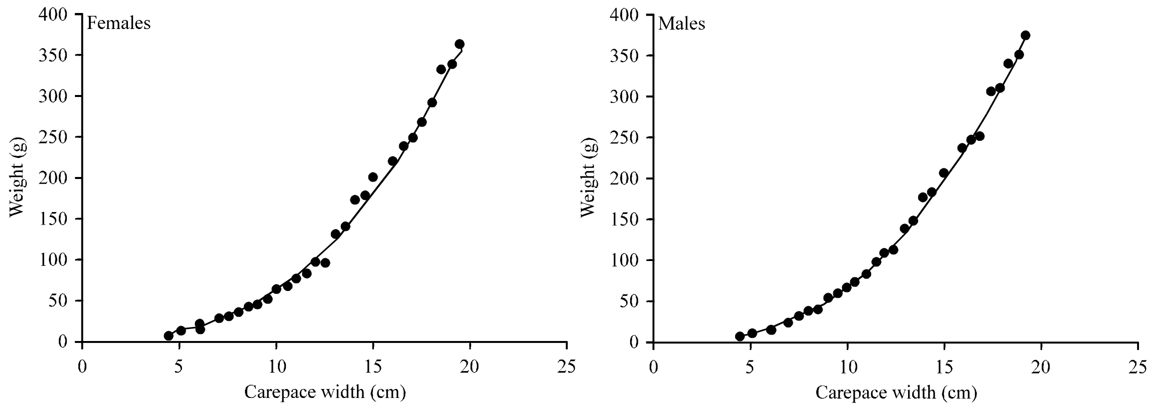

Fig. 3: Relative growth of female and male *P. trituberculatus* showing the relationships between carapace width and weight

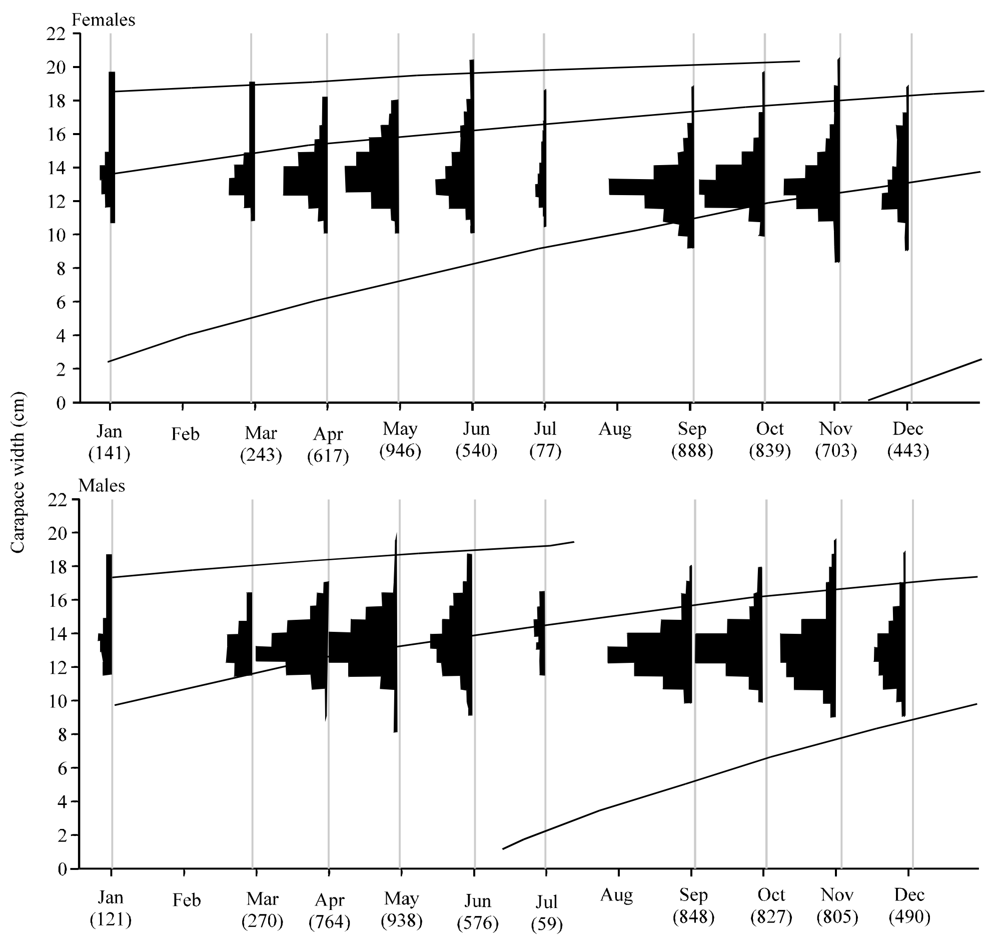

Fig. 4: Restructured carapace width-frequency data for female and male *P. trituberculatus* in West Sea of Korea with superimposed von Bertalanffy curves estimated by ELEFAN I

the corresponding parameters estimates summarized in Table 1. The analyses of modal progression for each sex separately showed that males grew faster and reached a larger size at equivalent age

Table 1: Parameters estimation of the elefan I analysis of carapace width-frequency data for females and males: CW∞, asymptotic width (cm); K, growth coefficient (year-1); tmax, longevity; φ', growth performance index

Sexes	CW_∞	K	t_{max}	φ'
Females	22.20	0.84	2.89	2.67
Males	22.40	0.94	2.49	2.76

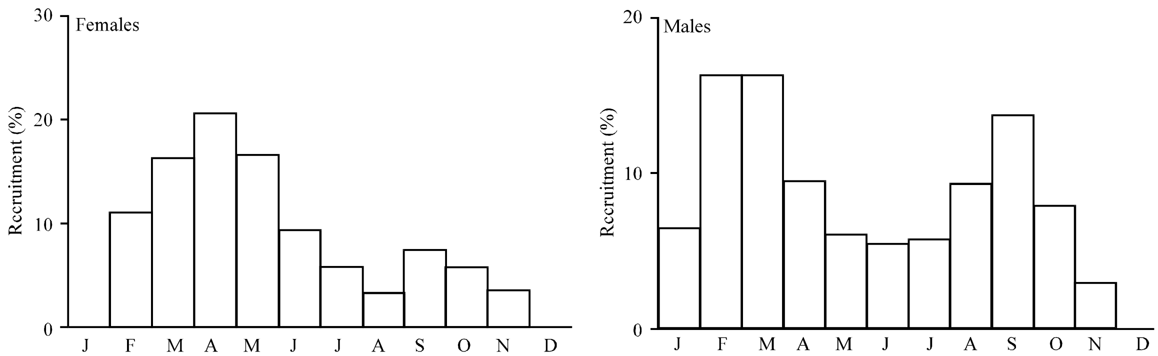

Fig. 5: Recruitment pattern of female and male *P. trituberculatus* identified by ELEFAN II routine

than females (K = 0.94 year^{-1} and CW_∞ = 22.40 cm for males and K = 0.84 year^{-1} and CW_∞ = 22.20 cm for females). Based on the growth performance indices (φ') females showed higher growth rates than males. The differences of φ' values (females: 2.76; males: 2.67) indicated a difference in growth pattern between the sexes. The phase of slow growth was evident during winter (December-February). Based on the growth parameters and the maximum carapace width, the maximum life span (t_{max}) was estimated to be 2.89 years for females and 2.49 years for males.

The structure of the recruitment patterns obtained by the ELEFAN II program indicated two normally distributed groups (April and September for females and March and September for males). However, it appears that recruitment does occur over nearly all the year (Fig. 5).

Mortality: Total mortality (Z) (±95% confidence limit), calculated from the length-converted catch curves, was 2.99 (±1.05) year^{-1} for females, 7.09 (±0.42) year^{-1} for males (Fig. 6) and a Jones and van Zalinge plot gave 5.32 (±0.14) year^{-1} for females, 7.27 (±0.20) for males (Fig. 7) are presented in Table 2. Z ranged from 2.99 to 5.32 year^{-1} and averaged 4.15±0.59 year^{-1} for females and from 7.09 to 7.27 year^{-1} averaging 7.18±0.31 year^{-1} for males. The natural mortality rates were computed using the growth parameter calculated in females and males from the methods proposed by Gislason *et al.* (2010) and Pauly (1980). Natural mortality (M) varied between the two methods; from 1.13 to 1.21 year^{-1} with an average of 1.17 year^{-1} for females and from 1.22 to 1.30 year^{-1} averaging 1.26 year^{-1} for males, respectively (Table 2). Finally, fishing mortality (F) was computed at 2.98 year^{-1} for females and 5.92 year^{-1} for males from the average of M and Z. The minimum and maximum fishing mortalities were recorded for the mid-carapace widths of 8.8 and 17.6 cm for females, respectively and 8.8 and 18.4 cm for males (Fig. 8), respectively. The exploitation ratio (E = F/Z) was 0.72 for females and 0.82 for males.

Yield-per-recruit (Y'/R) and biomass-per-recruit (B'/R): Based on the probabilities of capture, the estimated carapace width at capture was: females; CW_{25} = 9.96, CW_{50} = 10.43 and

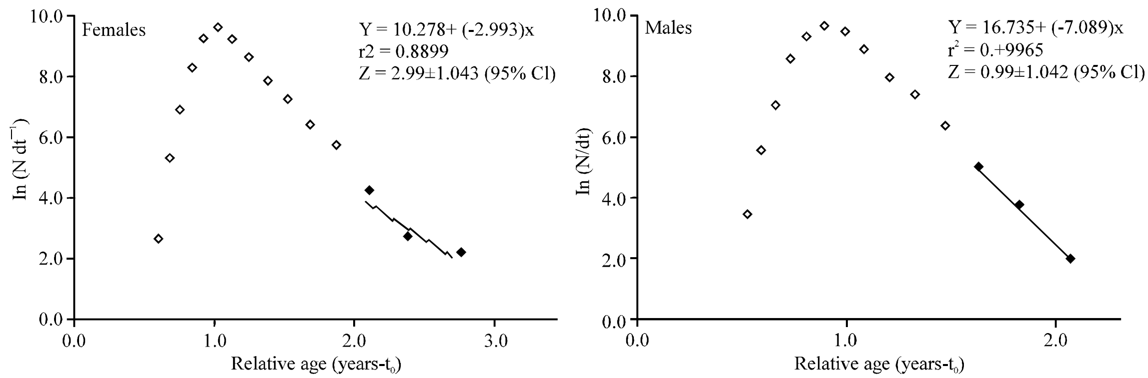

Fig. 6: Length-converted catch curves for female and male *P. trituberculatus* based on the parameters of the von Bertalanffy growth function (VBGF)

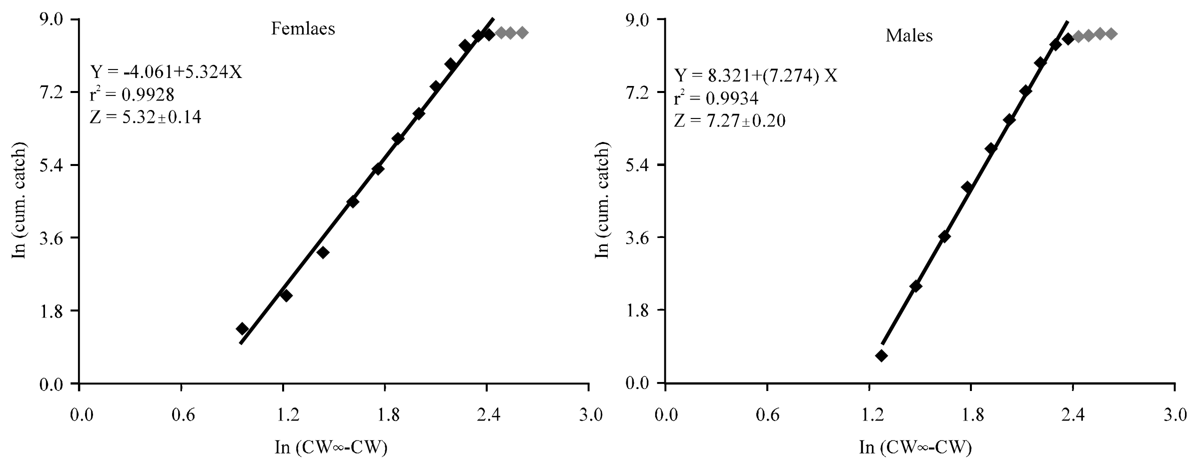

Fig. 7: Jones and Zalinge plot based on carapace width-composition data of female and male *P. trituberculatus*

Table 2: Total (Z year^{-1}) and natural (M year^{-1}) mortality estimated by two different methods and average values for female and male *P. trituberculatus* in the West Sea of Korea

	Z year^{-1}		
	Females	Males	Method
Average Z year^{-1}	2.99±1.05	7.09±0.42	Length-converted catch curve (Pauly, 1983, 1984)
	5.32±0.14	7.27±0.20	Jones and van Zalinge plot (Jones and Van Zalinge, 1981)
	4.15±0.59	7.18±0.31	
	M year^{-1}		
	Females	Males	Method
Average M year^{-1}	1.13	1.22	Gislason *et al.* (2010)
	1.21	1.30	Pauly (1980)
	1.17	1.26	

CW_{75} = 10.60 cm and males; CW_{25} = 12.29, CW_{50} = 12.97 cm and CW_{75} = 13.66 cm). The parameters CW_∞ and M/K (M/K = 1.39 for females and M/K = 1.34 for males) were used for the yield-per-recruit

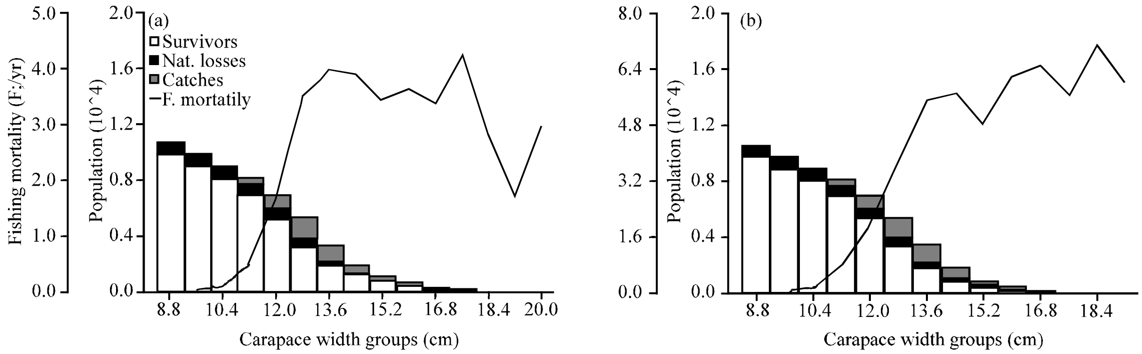

Fig. 8(a-b): Carapace width-structured virtual population analysis of (a) female and (b) male *P. trituberculatus*

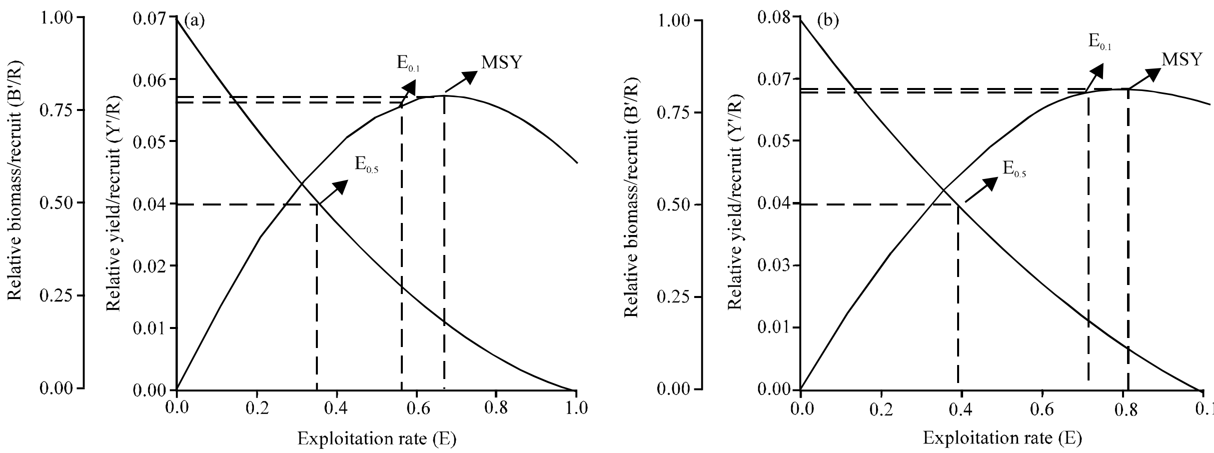

Fig. 9(a-b): Relative yield-per-recruit and biomass-per-recruit with exploitation rate of (a) female and (b) male *P. trituberculatus*

model. The yield-per-recruit and biomass-per-recruit curves, as functions of exploitation rate (E = F/Z), varied with the carapace width at capture (Fig. 9). The exploitation rate (E_{max}) that gave maximum relative yield-per-recruit was 0.67 for females and 0.80 for males. The exploitation rate ($E_{0.1}$) at which the marginal increase in relative yield-per-recruit is 10% of its value E = 0, was 0.56 for females and 0.70 for males. The exploitation rate ($E_{0.5}$) which corresponds to 50% of the relative biomass-per-recruit of unexploited stock was 0.35 for females and 0.39 for males. This indicates that Y'/R and B'/R are sensitive to changes in carapace width at capture (CW_c) and fishing intensity.

DISCUSSION

Data on the relationships between crab dimensions revealed a positive allometry between carapace width and weight. This means that individuals of this population become proportionally wider and heavier as growth proceeds. The positive allometric relationship between size and weight is well known among animal and is a direct consequence of the modification of the surface/volume ratios during growth (Turra *et al.*, 2002). On other hand, the positive or negative allometric relationship between carapace width and weight is not a general assumption among

P. trituberculatus (Bertini and Fransozo, 1999; Branco *et al.*, 2002). The West Sea of Korea's population of *P. trituberculatus* indicated that males grew faster and reached a larger size at equivalent age than females. This suggests that the difference in growth may be caused by relaxed competition, mortality and recruitment rates. According to these results, the aforementioned assumption that females growth slowdown coincides with their sexual maturation and spawning periods appears to be well-placed given that females start to invest energy in reproduction. The faster growth of males is in contrast to many other crustacean species which exhibit faster growth due to not having physiological responsibilities associated with egg production and incubation (Hartnoll, 1982). Alternative explanations for observed growth rates are influenced by discussion on the role of temperature. Temperature has a decisive effect on growth which is particularly evident in short lived species, such as crabs or other invertebrates (Cadman and Weinstein, 1988; Longhurst and Pauly, 1987; Hartnoll, 2001). However, temperature was the most important in explaining variation in growth rates and probably favoured the reproductive activity of *P. trituberculatus*, with increasing temperatures resulting in a faster growth rate. This is further reinforced by the percentage of individuals having a carapace width of ≥11.2 cm (Fig. 2). The results of this study point to two major recruitment events per year. However, understanding recruitment patterns is critical in managing marine populations effectively because they determine stock recruitment relationships, vulnerability to fishing pressure and habitat modification and the efficacy of marine reserves (Strathmann *et al.*, 2002).

Present results show that M is significantly related to carapace width and mean annual SST and M values were in higher males than in females. The total mortality (Z) of *P. trituberculatus* was high, with both methods used estimating similar total mortality for males, while a little different for females. Another explanation for the elevated estimate of total mortality in the West Sea of Korea is error caused by seasonal migrations and unique life cycle of *P. trituberculatus*. Estimates of mortality rates in the present study cannot be directly compared with from other areas, as methods, fishing gear and gear selectivity differ considerably. Our results have shown that natural mortality is lower and fishing mortality is higher than re-estimated results from Yeon *et al.* (1998) (Table 3). Found differences in mortality indicate that current *P. trituberculatus* population is more stressed than 12 years ago. Inducing factors are possible engendered by ecological, fishing pressure and environmental changes.

From the West Sea of Korea data an exploitation rate (E) of 0.79 for females and 0.86 for males was arrived at which is higher than the 0.5 optimum level of exploitation reported by Gulland (1971). The Y'/R model used in this study gives an absolute value of Y'/R but there are relative differences of Y'/R for varying values of fishing mortality and carapace width at capture (CW_c). The advantages of this model are that it requires fewer parameters and is especially suitable for assessing the effect of mesh size regulations (Sparre *et al.*, 1989).

In this study, we analyzed monthly carapace width-frequency data of *P. trituberculatus* and ascertained that it is a slow growing species. Slow growth suggests a high vulnerability to

Table 3: Comparison of the estimates of total (Z year^{-1}), natural (M year^{-1}) and fishing (F year^{-1}) mortality of *P. trituberculatus*

Sexes	Z	M	F	Reference
Pooled	3.32	1.40	1.92	Yeon *et al.* (1998)
Females	4.15	1.17	2.98	Present study
Males	7.18	1.26	5.92	

overfishing which calls for reliable fisheries monitoring and careful management of this resource. Our results appear to suggest that both body size and SST affect natural mortality. However, there are relatively few available data environmental variability and its effect on recruitment of *P. trituberculatus*. With the results obtained in this study, it is possible to discuss the influence of environmental factor and other aspects of population dynamics. It can be assumed that temperature and food availability are key growth factor, while body size is one of the causes of natural mortality. According to our results, there is clear need for identification recovery in response to exploitation and environmental variability, with a particular focus on the resilience of this species to exploitation. However, eventually more reliable estimates of biological parameters and fishing mortality are needed for a more rigorous assessment of the stock.

CONCLUSION

From the present study, it could be concluded that the stock of a local *P. trituberculatus* population under stress from heavy fishing pressure. There is an urgent need for further research to assess the rebound capacity of this species in response to ongoing exploitation pressure for the livelihood of the coastal communities of the area.

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