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Growth and population biology of the sand-bubbler crab *Scopimera crabricauda* Alcock 1900 (Brachyura: Dotillidae) from the Persian Gulf, Iran

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Abstract

Background: Dotillid crabs are introduced as one common dwellers of sandy shores. We studied the ecology and growth of the sand bubbler crab *Scopimera crabricauda* Alcock, 1900, in the Persian Gulf, Iran. Crabs were sampled monthly by excavating nine quadrats at three intertidal levels during spring low tides from January 2016 to January 2017.

Results: Population data show unimodal size-frequency distributions in both sexes. The Von Bertalanffy function was calculated at CWt = 8.76 [1 − exp (− 0.56 (t + 0.39))], CWt = 7.90 [1 − exp (− 0.59 (t + 0.40))] and CWt = 9.35 [1 − exp (− 0.57 (t + 0.41))] for males, females, and both sexes, respectively. The life span appeared to be 5.35, 5.07, and 5.26 years for males, females, and both sexes, respectively. The cohorts were identified as two age continuous groups, with the mean model carapace width 5.39 and 7.11 mm for both sexes. The natural mortality (M) coefficients stood at 1.72 for males, 1.83 for females, and 1.76 $years^{-1}$ for both sexes, respectively. The overall sex ratio (1:0.4) was significantly different from the expected 1:1 proportion with male-biased. Recruitment occurred with the highest number of annual pulse once a year during the summer.

Conclusions: The results, which show slow growth, emphasize the necessity of proper management for the survival of the stock of *S. crabricauda* on the Iranian coast of the Persian Gulf.

Keywords: Dotillid crabs, Sex ratios, Von Bertalanffy model, Persian Gulf

Background

Dotillid crabs are common dwellers of sandy shores, mangrove forests, estuaries, and brackish of tropical and subtropical regions (Ng, Guinot, & Davie, 2008; Wong, Chan, & Shih, 2010). The crab *Scopimera crabricauda* Alcock 1900 is a deposit feeder producing diurnally pseudofaecal pellets at sandy estuarine areas during low tide (Clayton & Al-Kindi, 1998; Gherardi, Russo, & Anyona, 1999). Sandy shores may be a favorable environment for crabs of the genus *Scopimera*, since habitats suitable for their foraging are the ones that enable them to sort sand with high efficiency and extract the small amount of organic material (Hartnoll, 1973) besides their abundance at muddy shores (Hartnoll, 1974). These crabs have the ability for inhabiting in the intertidal zone through morphological, physiological, and behavioral adaptations (Gherardi & Russo, 2001). They can display an isospatial strategy, which means changing location between exposure to air and water while remaining within a belt along the sea-land axis (Vannini & Cannicci, 1995).

Crustaceans including crabs, shrimps, and barnacles are ideal organisms for growth studies because precise measurements can be easily made on their exoskeleton in the field (Hartnoll, 1974; Ledesma, Molen, & Baron, 2010). These crustacea are easy to study their population

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dynamics (Chan & Williams, 2004; Silva et al., 2019; Sousa et al., 2021). Various methods have been applied to model crab growth including mark-recapture (Diele & Koch, 2010), rearing (Kondzela & Shirley, 1993), and length-frequency data analysis (Sharifian, Kamrani, Safaie, & Sharifian, 2017). Length-frequency analysis is an appropriate choice for estimating growth since it relates to data-limited experiments (Chan & Williams, 2004; Safaie, Kiabi, Pazooki, & Shokri, 2013). Overview of previous studies showed the importance of estimating growth for predicting the size of species at a certain age (Sparre & Venema, 1992); for modeling population dynamics (Hoggarth et al., 2006), for providing valuable data about lifespan, age at recruitment, maturity, and cohort identification (Sharifian, Kamrani, et al., 2017); and for the development of effective management programs (Dalu et al., 2016). Moreover, the population dynamics of organisms can provide baseline data for predicting the effect of global warming on their geographical distribution range (Sanda, Hamasaki, Dan, & Kitada, 2019; Wakiya, Itakura, & Kaifu, 2019).

Previous studies reflect a few number of researches on the population structure of crabs of the genus *Scopimera* (Clayton & Al-Kindi, 1998; Gherardi & Russo, 2001; Gherardi, Russo, & Lazzara, 2002; Sharifian, Malekzadeh, Kamrani, & Safaie, 2017; Wada, Ashidate, Yoshino, Sato, & Goshima, 2000), with most studies performed on the distribution (Fielder, 1971), and breeding biology (Wada, 1981; Yamaguchi & Tanaka, 1974). In the present study, the population ecology, growth, mortality, and sex ratio of sand-bubbler crab *S. crabricauda* using length-frequency data were examined from Persian Gulf, Iran.

Methods

Study site and collection of data

The sampling area is sandy shores of the Persian Gulf, the sandy coasts of the main park of Bandar Abbas (27°11′N 56°20′E) (Fig. 1), the south of Iran. The climate of this area is tropical, and the annual water temperature varies from 22 to 38 °C.

Samples were taken monthly from January 2016 to January 2017. The sampling was performed by excavating nine quadrats (100 × 100 × 20 cm deep; three for each intertidal level) in high-density areas of open burrows, and collecting the crabs after sieving the sand (Hails & Aziz, 1982) at three intertidal levels -low, mid and high- during spring low tides. At the sampling site, crabs were sexed and counted for each intertidal level.

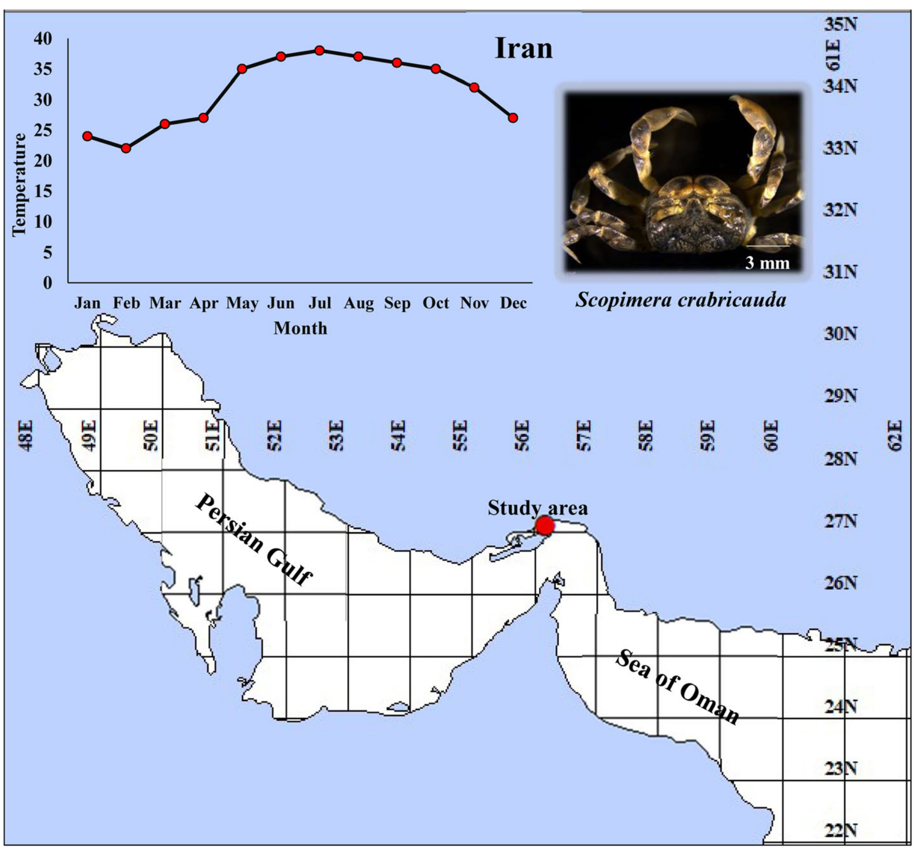

Fig. 1 Sampling locations in southern Golshahr, Bandar Abbas, Persian Gulf

The carapace width (CW) and carapace length (CL) were measured using a Vernier caliper (± 0.01 mm accuracy), with terminology based on Ng (1988). The total body weight TW was measured in a standard electric balance with 0.0001 g accuracy. Then, the crabs were released back into the field.

Size-frequency distribution

The crabs were grouped into 11 (0.5 mm) CW classes (3–3.5 to 8–8.5 mm) with the number and range of size classes based on the best fit of the growth models.

Growth

Von Bertalanffy growth function was used to describe the growth of crab (Ricker, 1975) as the following:

$$\mathrm{CW}_t = \mathrm{CW}_\infty \left(1 - e^{-K\,(t - t_0)}\right),$$

where CW_t is defined as the length at time t, t_0 as the age at zero length, CW∞ as the asymptotic length, and K as the growth rate of crab. The data of length frequency were input into the program FiSAT and the parameters CW∞ and K were estimated by the ELEFAN1 method. The t_0 was calculated by Pauly's empirical equation (Pauly, 1983).

$$\log(-t_0) = -0.3922 - 0.2752\,\log(\mathrm{CW}\infty) - 1.038\log K$$

The separation of length-frequency composition into its age groups was performed by the Bhattacharya method (Bhattacharya, 1967). The growth performance of crabs was calculated by Munro's Index (Φ′) (Pauly & Munro, 1984) as the following:

$$\Phi' = \log K + 2 \times \log \mathrm{CW}\infty$$

Munro's Index (Φ′) can be applied for comparison of the growth between the different sexes or the species along latitudinal gradients or among taxonomic groups.

Mortality, the maximum long life (T_{max}), and sex ratio

Pauly's empirical formula (Pauly, 1980) was used to calculate the rate of natural mortality (M) as the following:

$$\mathrm{Ln}\,(M) = -0.0152 - 0.279\ \ln(\mathrm{CW}\infty) + 0.6543\ \ln(K) + 0.4634\ \ln(T)$$

where T is the mean water temperature (°C), with the range of 25 to 35 °C in the study area.

The equation T_{max} = (2.996/K) (Taylor, 1958) was applied for calculating the maximum long life (T_{max}).

The sex ratio was assessed by a chi-squared test (χ^2) for the detection of a significant deviation from a 1:1 sex ratio by month ($p < 0.05$).

Results

The size-frequency distributions of both sexes showed the maximum frequency of male and female crabs in the range 6.0–6.5 and 5.0–5.5, respectively, extending to at least 3.0–3.5 mm (Fig. 2).

The overall sex ratio recorded was 1:0.4 and was significantly different from the expected 1:1 proportion (chi-square test, p = 0.00) with male-biased. However, in some months, January (2016) and March, the sex ratio was not significantly different than the expected ratio (Table 1).

The K value was 0.56, 0.59, and 0.57 years^{-1}, with a CW∞ of 8.76, 7.90, and 9.35 mm for males, females, and both sexes, respectively (Fig. 3). Moreover, five and four cohorts were recognizable (black line) for males and females, respectively in Fig. 4. The estimated age of *S. crabricauda* at the first juvenile stage (t_0) was – 0.39, – 0.40, – 0.41 years for males, females, and both sexes, respectively. Using the Bhattacharya method, age groups (cohorts) (with the mean of carapace width for each cohort) of *S. crabricauda* were identified (Table 2; Fig. 4). The age groups are seen as almost being continuous groups, which is characteristic of a long-lived species (Fig. 4a–d). Using this method, one age group (cohort) for males and females was identified with the mean model carapace width of 6.22 and 5.45 mm, respectively (Table 2, Fig. 4a, b), as well as two age groups with the mean model carapace width 5.39 and 7.11 mm for both sexes (Table 2; Fig. 4c, d). Recruitment occurred with the highest number of annual pulse once a year during the summer and on the relative strength of juveniles at June with 19.66%, reaching a minimum in September with 2.39 % (Fig. 4e). The calculated Munro's Index (Φ) was 1.63, 1.56, and 1.70 with natural mortality estimated at 1.72, 1.83, and 1.76 (years^{-1}) for males, females, and both sexes, respectively, based on the mean water temperature of the different months (ranging from 22 to 38 °C).

The growth equation of *S. crabricauda* based on Bertalanffy's model allowed the determination of the relationship between the inner carapace width and age (Fig. 5) with the growth curve CWt = 8.76 [1 – exp (– 0.56 (t + 0.39))] for males, CWt = 7.90 [1 – exp (– 0.59 (t + 0.40))] for females, and CWt = 9.35 [1 – exp (– 0.57 (t + 0.41))] for both sexes, respectively.

According to the obtained growth curves, the carapace width in the first, second, third, fourth, and fifth years was estimated to be 4.73, 6.46, 7.44, 8.01, and 8.33 mm, for males; 4.44, 5.98, 6.83, 7.31, and 7.57 mm, for females; and 5.15, 6.98, 8.01, 8.59, and 8.92, for both sexes, respectively (Fig. 5). The estimated maximum lifespan was 5.35, 5.07, and 5.26 years for males, females, and both sexes of *S. crabricauda*, respectively.

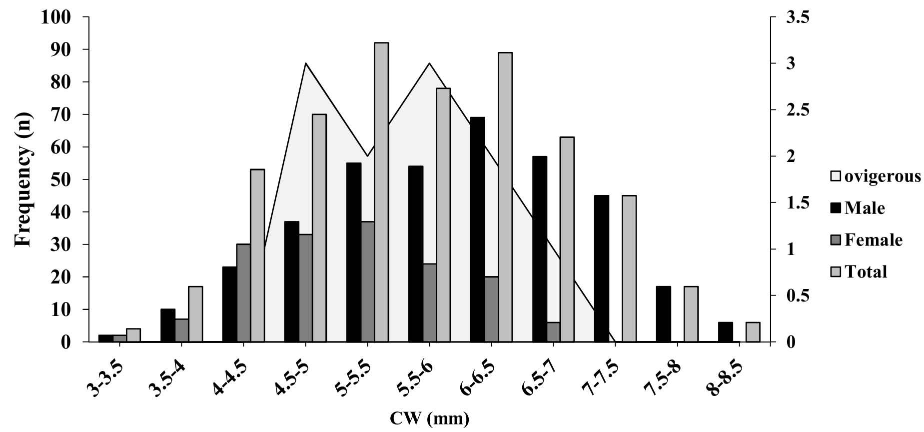

Fig. 2 Relative frequency of crab *S. crabricauda* in Persian Gulf (distribution in 11 and 8 carapace width (CW) classes for male and female crabs, respectively)

Discussion

The size-frequency distribution of *S. crabricauda* was unimodal for both sexes. A unimodal frequency distribution was also found in the population of two Dotillid crabs *Scopimera crabricauda* and *Dotilla sulcata* Forskåll 1775 in an estuarine habitat in Oman (Clayton & Al-Kindi, 1998), sand bubbler crab *Dotilla fenestrata* Hilgendorf 1869 in the mangrove swamp of Kenya (Gherardi et al., 2002; Gherardi & Russo, 2001) and the population of *Scopimera globosa* De Haan, 1835 from Japan (Yamaguchi & Tanaka, 1974). However, the distribution *Scopimera globosa* and *Ilyoplax pusillus* De Haan, 1835 was reported bimodal from the estuary of Waka river, Japan (Wada, 1981) reflecting seasonal mortality pulses and behavioral differences in harsh environmental conditions (Thurman, 1985). Moreover, Wada (1981) reported the size-frequency distribution can show the density of crabs, so that the large sex-able crabs show the lower densities on the whole. In regard to the above-mentioned cases about the unimodal distribution in the most dotillid crabs, it seems the size-frequency distribution of *S. crabricauda* is not the exception in terms of unimodal distribution. We also observed a clear sexual dimorphism, with males larger than females (Sharifian, Malekzadeh, et al., 2017) in agreement with the finding of Clayton and Al-Kindi (1998), Kobayashi and Archdale (2020), and Hamasaki, Osabe, Nishimoto, Dan, and Kitada (2020).

The overall sex ratio here for *S. crabricauda* was significantly different from the expected 1:1 ratio. The varied reasons were reported for a significant difference of sex ratio including differential primary distribution (Fielder, 1971), mortality (Wada et al., 2000), lifespan, migration, food restriction, the utilization of habitats (Johnson, 2003), the behavior of the feeding, and the emergence during low tide between the sexes (Fielder, 1971). It was reported that deviations from the 1:1 sex ratio can affect the reproductive potential of the population and regulate the population size (Lardies, Rojas, & Wehrtman, 2004). The sex ratio of *S. crabricauda* was found to be similar to *Scopimera inflata* Milne-Edwards, 1873 from the sandy beaches of the eastern Australian coast (Fielder, 1971) and different with two dotillid crabs *Scopimera crabricauda* and *Dotilla sulcata* from an estuarine habitat in Oman (Clayton & Al-Kindi, 1998). The differences in primary distribution and the feeding behavior between sexes of *S. crabricauda* may be the reason for different sex ratio.

In the population studies, the mean length (in crabs, width carapace) of infinitely old crabs in population be defined as the asymptotic length (L_∞) and subsequently, growth rate (K) be determined as the rate approaching of crab to its asymptotic length (L_∞). The crabs showing high growth rate have properties including a short-lived, the

Table 1 Sex ratio and absolute monthly frequencies of crab *S. crabricauda* by sex in Persian Gulf

Month	Male	Female	Sex ratio	Chi test
January (2016)	21	33	1:1.57	(p = 0.10)
February*	43	12	1:0.28	(p = 0.00)
March	22	26	1:1.18	(p = 0.56)
April*	36	14	1:0.39	(p = 0.00)
May*	29	13	1:0.45	(p = 0.01)
June*	28	5	1:0.18	(p = 0.00)
July*	38	10	1:0.26	(p = 0.00)
August*	25	3	1:0.12	(p = 0.00)
September*	21	6	1:0.29	(p = 0.00)
October*	21	7	1:0.33	(p = 0.01)
November*	31	10	1:0.32	(p = 0.00)
December*	30	9	1:0.30	(p = 0.00)
January (2017)*	30	11	1:0.37	(p = 0.00)
Total*	375	159	1:0.42	(p = 0.00)

*Significant differences from the 1:1 ratio (chi-square test, $P < 0.05$)

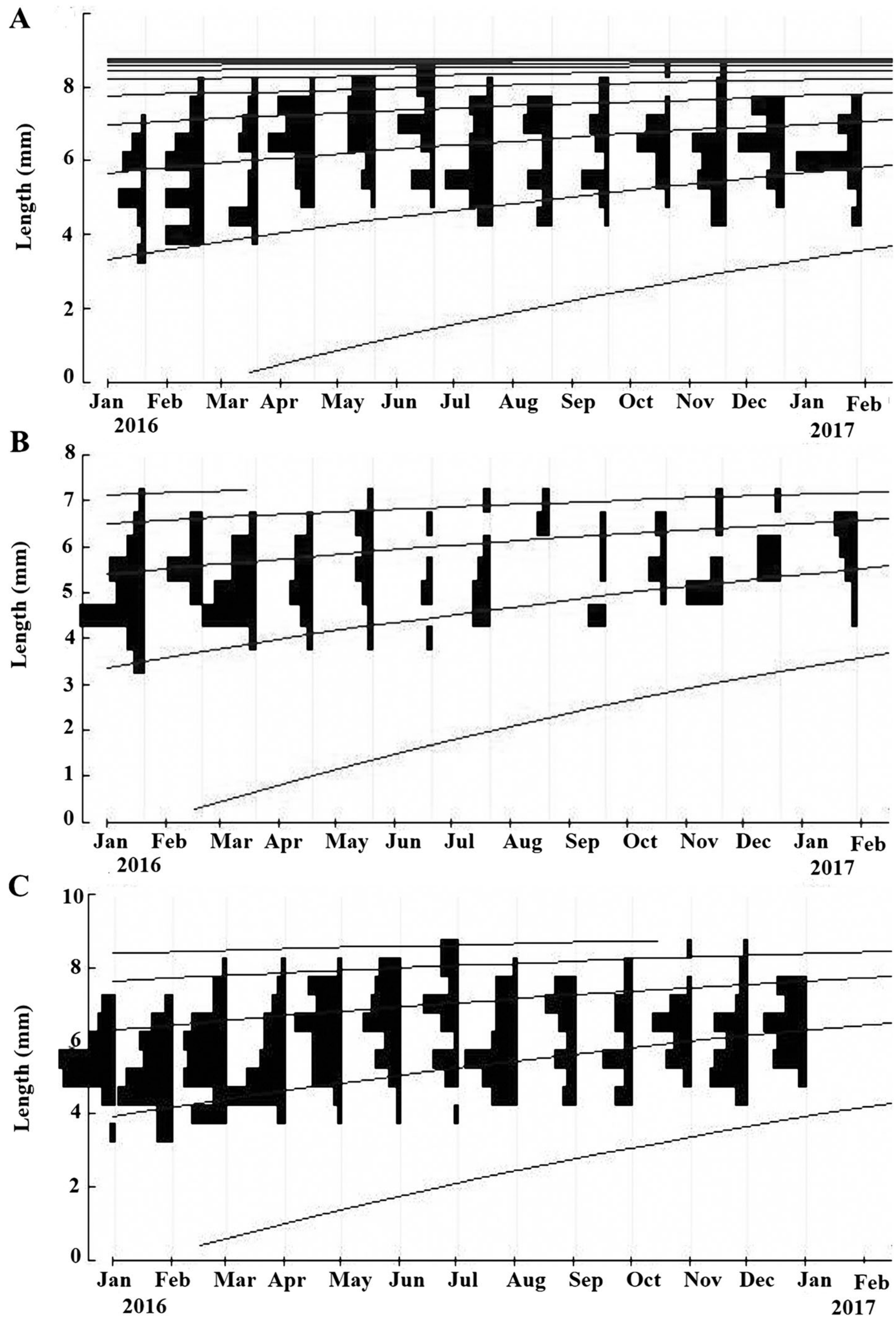

Fig. 3 Carapace-width frequency distribution with growth curves from **a** males, **b** females, and **c** both sexes of *S. crabricauda* in Persian Gulf (note the black lines representing the cohorts)

achieving to the asymptotic length ($L\infty$) within one or two years, and the continual growth during the year (Koch, Wolff, & Diele, 2005). On the contrary, crabs with a low growth rate (K) show a flat growth curve. The relatively low growth rate and a long lifespan of *S. crabricauda* reflect its slow growth. It is obvious the effect of temperature on the growth and the reproduction of crabs (Wolcott, 1988).

The age at zero length (t_0) of *S. crabricauda* showed a negative value indicating more rapid growth of juveniles than adult crabs (King, 1995). Given that crab *S.*

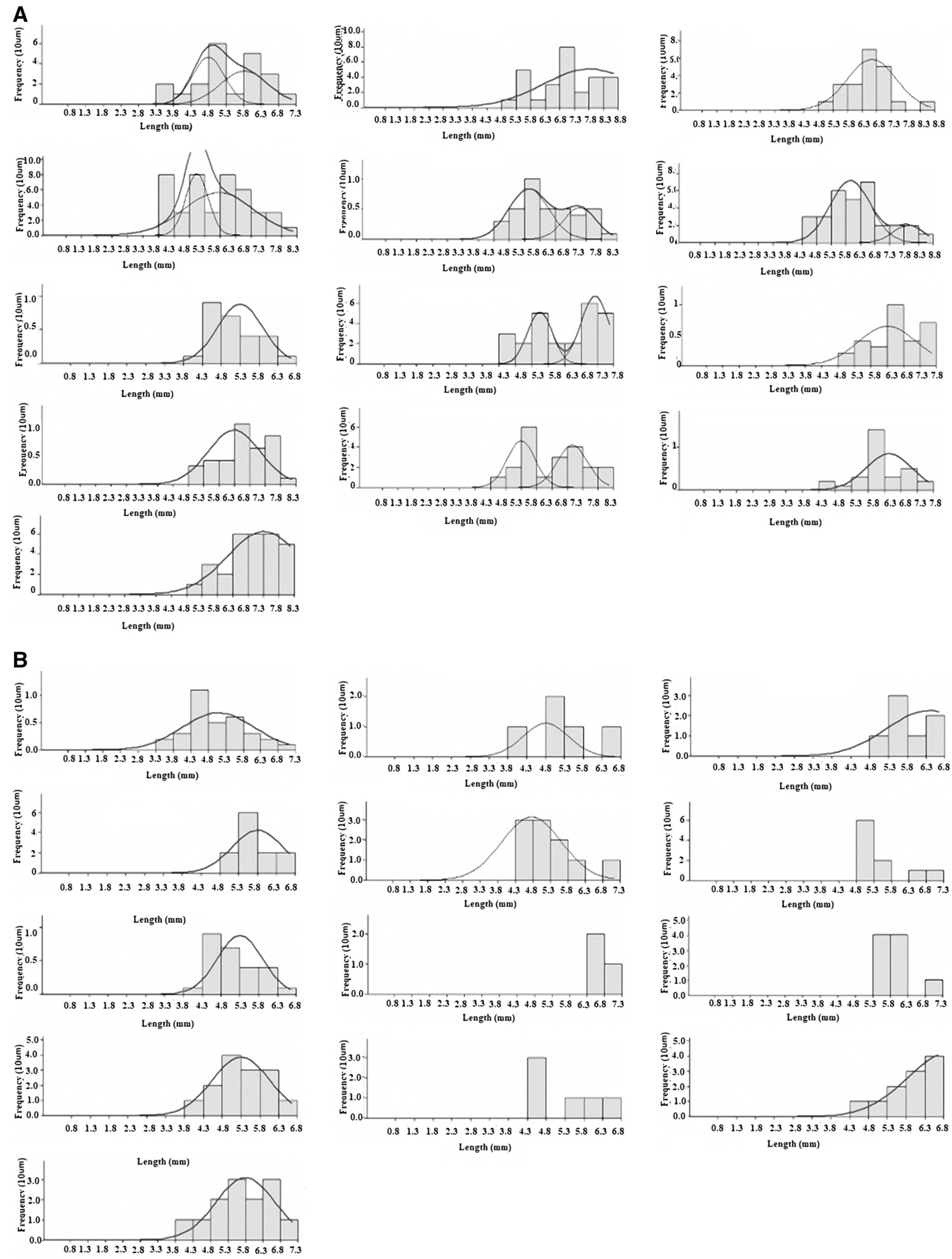

Fig. 4 Composite distributions of the pooled width-frequency composition from **a** males, **b** females, **c** both sexes of *S. crabricauda*, identified by the Bhattacharya (1967) method, for each month, and **d** for both sexes through years, as well as **e** pattern recruitment of both sexes (note that each curve represents one age group)

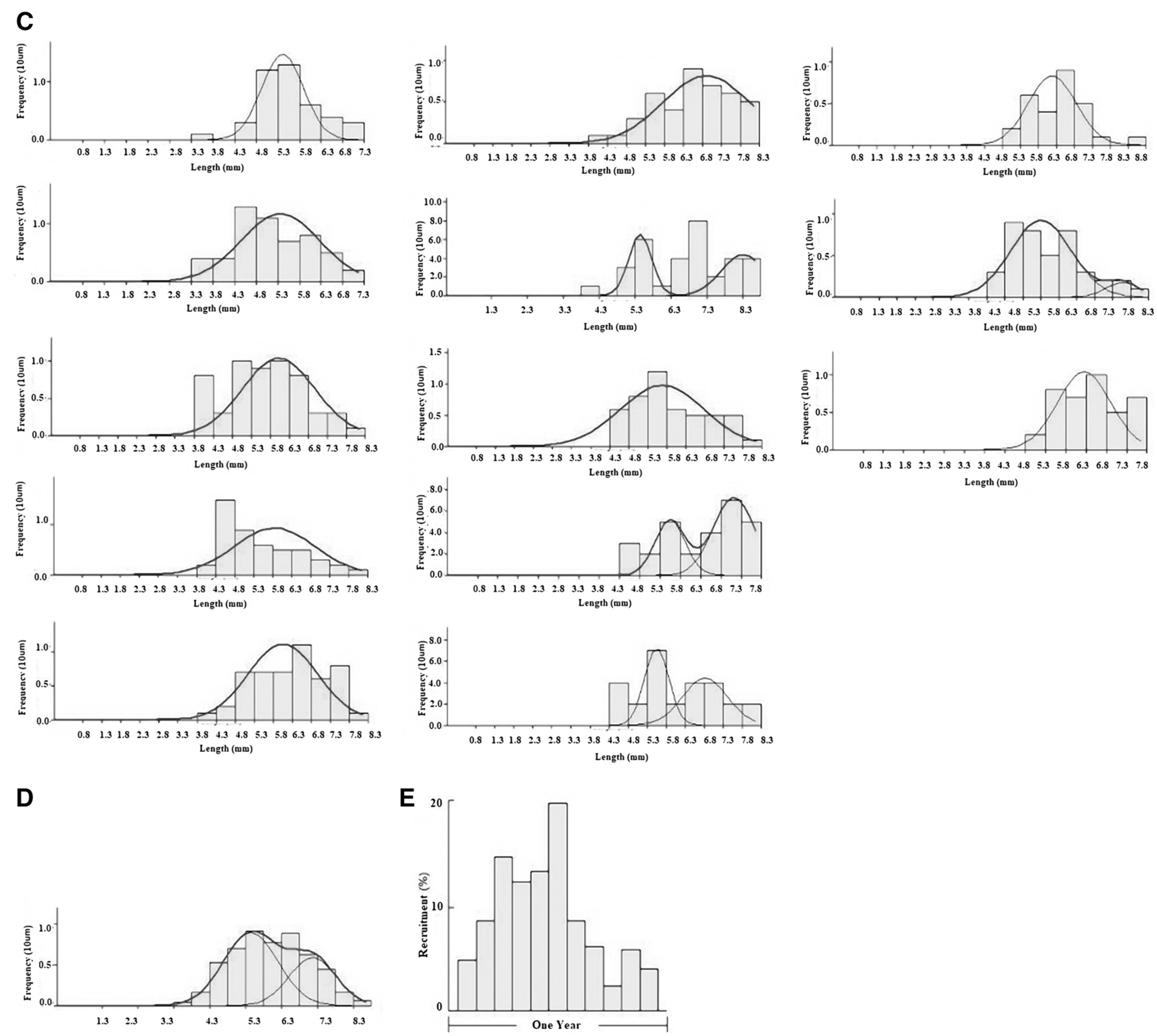

Fig. 4 *(Continued)*

crabricauda is a marine crab and in most aquatic organisms, juvenile individuals have a higher growth rate than adult ones, it seems this crab is not the exception from this general principle.

The estimated Munro's Index (Φ) of crab *S. crabricauda* was 1.63 and 1.56 for males and females, respectively. The most important function of this index is the comparison the growth rate of isomorph crabs so that it is nearly constant for the same species (Pauly & Munro, 1984).

The reproduction and rapid recruitment can change the size-frequency distribution of a population during the year (Tao, 1994). We observed high recruitment for juveniles of *S. crabricauda* during summer which declines in autumn. The highest number of ovigerous *S. crabricauda* was observed from March to April during spring (Sharifian, Malekzadeh, et al., 2017). According to reach to the maximum ovigerous *S. crabricauda* in April, it expected the existence peak of recruitment in June. Moreover, the changing in concentrations of nutrients in the environment can affect the pulse of recruitment (Sharifian, Kamrani, et al., 2017).

The estimated natural mortality rate of crab *S. crabricauda* was 1.72 and 1.83 (years^{-1}) for male and female crabs, respectively. Although, in studies of population dynamics, a natural mortality rate is one of the basic parameters difficult to estimate accurately; however, its value has been reported mostly between 1.5 and 2.5 depending on the environment and the species (Beverton & Holt, 1959). In this respect, it can be stated natural mortality rate of

Table 2 Summary of the growth parameter estimates of crab *S. crabricauda* (mean = mean of carapace width; S. D = standard deviation; S. I = separation index). M: male; F: female, B: both sexes

Mean (M)	S.D	Population	S.I	Mean (F)	S.D	Population	S.I	Mean (B)	S.D	Population	S.I
5.53	0.90	20.00	n. a	5.17	0.95	34	n. a	5.36	0.48	35.79	n.a
5.97	1.16	42.00	n. a	5.50	0.34	11	n. a	5.31	0.90	53.12	n.a
6.38	1.55	29.14	n. a	5.25	0.60	26	n. a	5.97	0.95	49.21	n.a
6.24	0.84	38.00	n. a	5.25	0.76	15	n. a	5.80	1.06	50.02	n.a
7.25	1.18	37.04	n. a	5.75	0.84	13	n. a	6.00	0.91	50.68	n.a
7.77	1.61	40.92	n. a	4.42	0.85	5	n. a	6.85	1.14	46.50	n.a
5.39	0.64	26.72	n. a	4.72	0.85	13	n. a	5.39	0.32	10.58	n.a
7.04	0.53	13.81	2.16					8.25	0.60	13.27	2.68
7.50	0.37	9.59	n. a	–	–	–	n. a	5.63	1.10	54.07	n.a
7.18	0.42	14.24	2.30								
5.25	0.45	10.53	n. a	–	–	–	n. a	5.50	0.37	9.59	n.a
6.91	0.49	10.35	2.25					7.07	0.51	18.60	2.23
6.25	0.66	21	n. a	6.32	1.11	13	n. a	5.50	0.32	11.59	n.a
								6.77	0.59	13.07	2.12
5.90	0.69	24.85	n. a	–	–	–	n. a	6.13	0.67	27.84	n.a
7.89	0.52	5.24	2.24								
6.26	0.87	28.19	n. a	–	–	–	n. a	5.75	0.84	38.94	n.a
								8.01	0.45	3.97	2.30
6.90	0.69	29.58	n. a	6.89	1.11	23.50	n. a	6.20	0.66	34.43	n.a

crab *S. crabricauda* is relatively high. The natural mortality rate can be related to the relative abundance of predators in the environment (Safaie et al., 2013), growth rate (Sparre & Venema, 1992), and reproduction (producing more eggs in species with higher natural mortality rate) (Gunderson & Dygert, 1988). Considering that intertidal habitat and high environmental fluctuation, besides the reporting of dotillid crabs producing high eggs (Yamaguchi & Tanaka, 1974), the relatively high natural mortality of crab *S. crabricauda* is reasonable.

Conclusions

Considering the habitat of *S. crabricauda* (sandy coast of the main park at Bandar Abbas), subsequently susceptibility of crab to various types of environmental pollution (including plastic waste, urban sewage as reported main

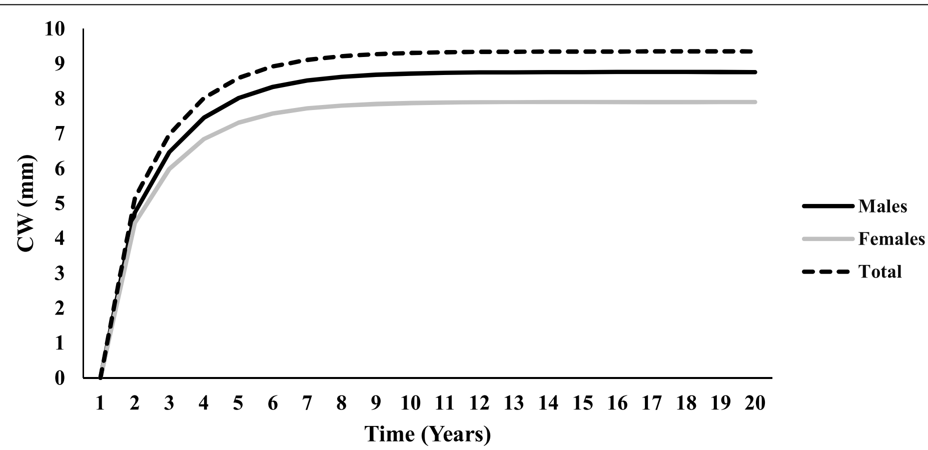

Fig. 5 Growth curves of in crab *S. crabricauda* in Persian Gulf (note the increasing process until arriving at an asymptotic length (CW∞) identified by the straight line)

challenges in this park) and with reference to the results of our study, which predict a slow growth for this species, it seems that the crab's storage has a long-term recovery potential. Therefore, proper management is critical for the conservation stock of *S. crabricauda* as benthic ecological indicators in coasts of Persian Gulf, Iran.

Abbreviations
CW: Carapace width; CL: Carapace length; TW: Total weight

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Authors' contributions
S.S: Statistical analysis, writing the paper; V.M: Data collection, data preparation; E.K. and M.S: The guidance in the methods and results. All authors have read and approved the manuscript.

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Availability of data and materials
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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