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Carapace width-weight relationship, age, growth and longevity of the mud crab *Scylla olivacea* (Herbst, 1796) in the Pichavaram mangroves, south-east India

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The present study provides novel information on carapace width-weight (CWR) relationship and growth parameters of the mud crab Scylla olivacea *(Herbst, 1796) inhabiting the Pichavaram mangroves, east coast of India based on length frequency data sets during June 2010 to May 2012. CWR revealed linear regression between carapace width and weight in both sexes, and overall CWR exponent (b) values acquired for males and females are 3.035 ($r^2 = 0.962$) and 2.925 ($r^2 = 0.933$) respectively. The growth parameters, CW_∞, K and t_o derived for males and females were 148.05, 0.762 year^{-1} and −0.637 and 138.80 mm, 0.856 year^{-1} and −0.681 respectively. The growth of* S. olivacea *was assessed through various methods in such a way that the outcome of one method functions as a rider, check and control over the other.*

Keywords: CWR, *Scylla olivacea*, Pichavaram, mud crab, growth

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INTRODUCTION

Indo-west Pacific mud crabs of the genus *Scylla* are large commercially important portunids that are typically associated with mangroves and have been overexploited in many countries of South-east Asia for the past three decades (MacNae, 1968; Angell, 1992; Keenan, 1999; Le Vay *et al.*, 2007; Mirera, 2011). In addition to high fishing pressure, there are other factors determining the present status of mud crab stocks in South-east Asia, such as conversion of mangrove areas for large-scale shrimp farming, fishing of gravid females for high market value, capture of undersized crabs, collection of wild seeds for pond culture and, finally, not all the countries involved have any rules and regulations for mud crab fishing. Recently, the genus *Scylla* was recognized with four species (*S. serrata, S. tranquebarica, S. olivacea* and *S. paramamosain*); previously the genus was alleged to have only one species (Keenan *et al.*, 1998). Previous literature on *Scylla* spp. is uncertain because of the identity of the species except in South Africa where *S. serrata* is the only known species (Le Vay *et al.*, 2007).

Length-weight relationships and growth parameters have great importance for estimating the population size of a stock for exploitation purposes. In addition, they play a vital role in implementing effective management strategies for the sustainable development and judicious exploitation of the resources (Bal & Rao, 1984). Growth in crustaceans is a discontinuous process in which body size increases only at the time of moulting. Therefore, age determination in decapods often relies on the associated growth models. Methods of age determination in crustaceans involve the observation of specimens in captivity, tagging and recapture, length-frequency distribution analyses in wild populations, analysis of data on moult increment and inter-moult duration and assessment of the age pigment 'lipofuscin' in the brain (Hartnoll, 2001; Maxwell *et al.*, 2007; Vogt, 2011). However, length-frequency data have been widely used in studying ageing and growth parameters of crustaceans because it is a quick and reliable method.

The present study deals with the CWRs, age and growth parameters of *S. olivacea* found in the Pichavaram mangroves on the south-east coast of India based on length-frequency data where this species is dominant in catch over other mud crabs.

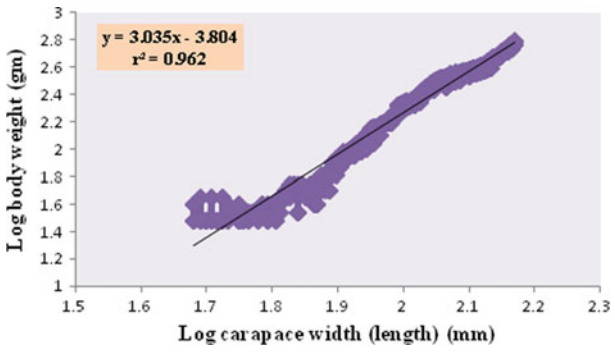

Fig. 1. Logarithmic relationship between carapace width (length) and weight of male *Scylla olivacea*.

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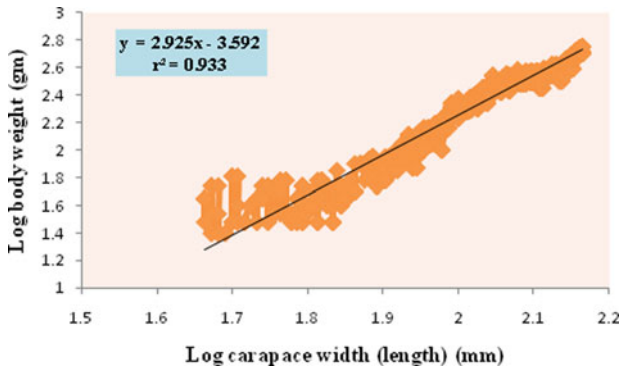

Fig. 2. Logarithmic relationship between carapace width (length) and weight of female *Scylla olivacea*.

Table 1. Summary of estimated growth parameters (CW_∞ and K) of *S. olivacea*.

Method	Sex	CW_∞ (mm)	K year^{-1}
Powell Wetherall	M	148.79	–
	F	139.27	–
ELEFAN I			
(i) Automatic scan	M	148.15	1.10
	F	138.80	1.00
(ii) K-scan	M	148.05	1.20
	F	138.60	1.40
Ford-Walford	M	148.05	0.762
	F	138.60	0.856
Gulland and Holt	M	148.05	1.138
	F	138.60	2.043
Munro	M	148.35	2.216
	F	138.72	2.321

MATERIALS AND METHODS

Sampling

Specimens of mud crab *Scylla olivacea* were collected from the commercial fish landing centres around the Pichavaram mangroves located on the south-east coast of India (11°29′N 79°46′E), during June 2010 to May 2012. The species was confirmed by both molecular and morphometric level (Viswanathan *et al.*, 2012). A total of 2895 specimens of *S. olivacea*, comprising 1468 males and 1427 females were analysed for CWR, while for age and growth a total of 6094 crabs comprising 3372 males and 2722 females were analysed. Collected crabs were measured individually for carapace width (space between the tips of the 9th antero-lateral spines across the body) and weight to the nearest 1 mm and 1 g respectively. The length-frequency data for males and females of each sampling day were classified into 8 mm size intervals, then these data were pooled on a monthly basis (Sekharan, 1962). A total of 13 and 12 size groups or class sizes (with 8 mm intervals) were obtained for males and females respectively.

Statistical analysis

CWR was determined by employing the Le Cren's (1951) non-linear equation ($W = aL^b$), where W = body weight in g, L = length in mm and a, b = parameters that were estimated by employing linear regression analysis. Regression analysis was used to determine the constants, 'a' and 'b' values and relationships between carapace width (length) and weight with the aid of Microsoft Excel (MS-Excel 2007). Further, analysis of variance (ANOVA) was performed to test the significance of the difference between regression coefficient values (by value) at the 5% level for both sexes.

The von Bertalanffy growth function (VBGF) was used for describing age and growth of mud crab *S. olivacea*. The simplest version of this function is:

$$L_t = L_\infty(1 - e^{-K(t-t_o)})$$

As crabs grow width wise, their length is termed the carapace width (CW), so hereafter 'L' will be replaced by 'CW', then the VBGF function can be expressed as:

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

where, CW_∞, asymptotic carapace width attained by the crab; K, growth constant (coefficient of catabolism); t_o, age the crab would have at length 0, if they had grown as per the equation; CW_t, predicted carapace width at age 't'.

Age and growth studies were carried out in the FiSAT II software package, introduced by Pauly & David (1981).

RESULTS

Carapace width-weight relationship

The exponent (b) values obtained for males and females are 3.035 ($r^2 = 0.962$) and 2.925 ($r^2 = 0.933$), respectively. This indicates that there exists a linear increase in weight per

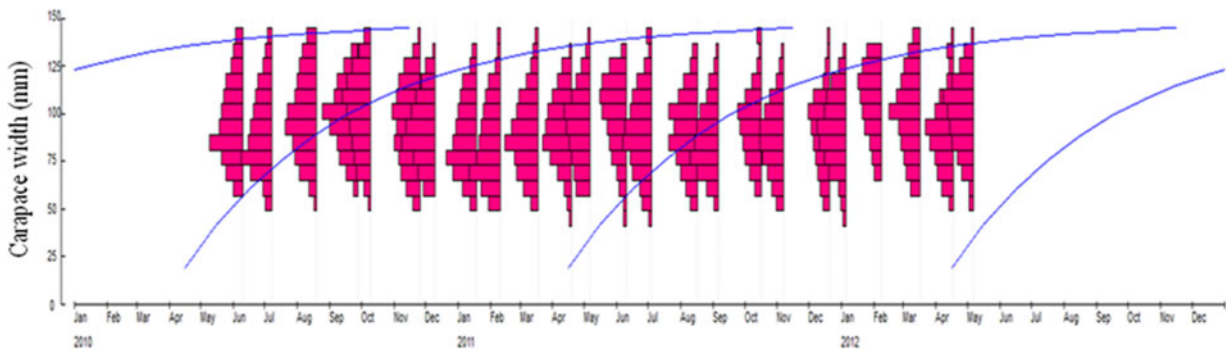

Fig. 3. ELEFAN I plot for male crabs.

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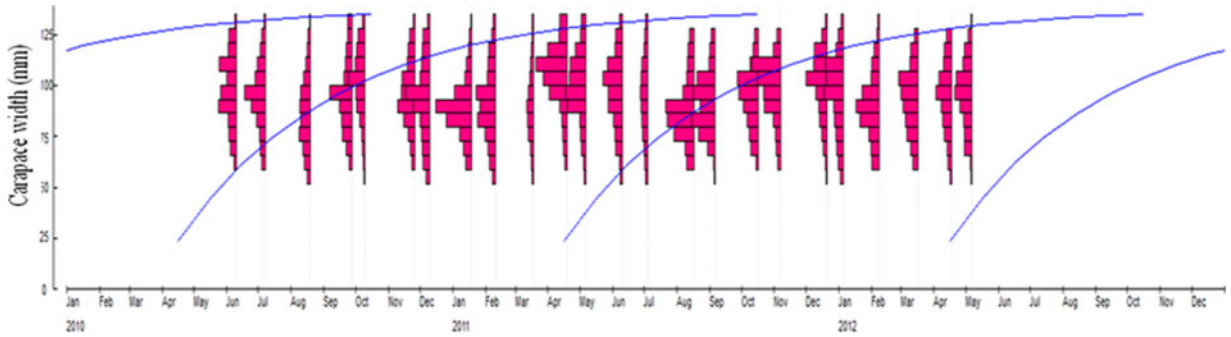

Fig. 4. ELEFAN I plot for female crabs.

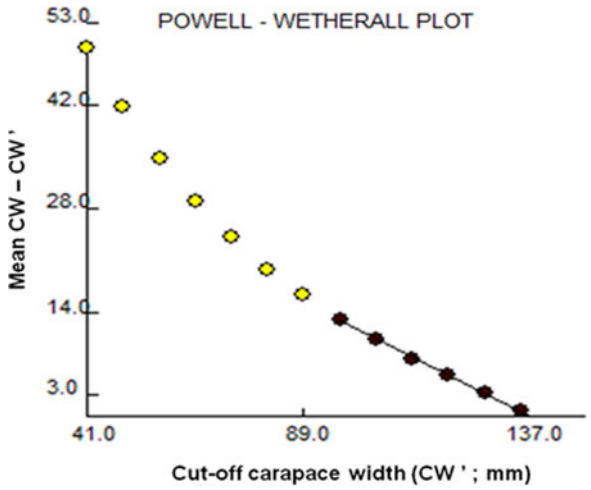

Fig. 5. Powell-Wetherall plot of male crabs.

unit increase in carapace width of 3.035 and 2.925 units for males and females, respectively. The CWRs curves fitted separately for males and females were derived by plotting the observed values of carapace width (length) against weight and are shown in Figures 1 and 2, respectively. The regression line plotted from the data showed a straight-line (linear) relationship between the observed and calculated values of the two variables carapace width (length) and weight. The CWRs

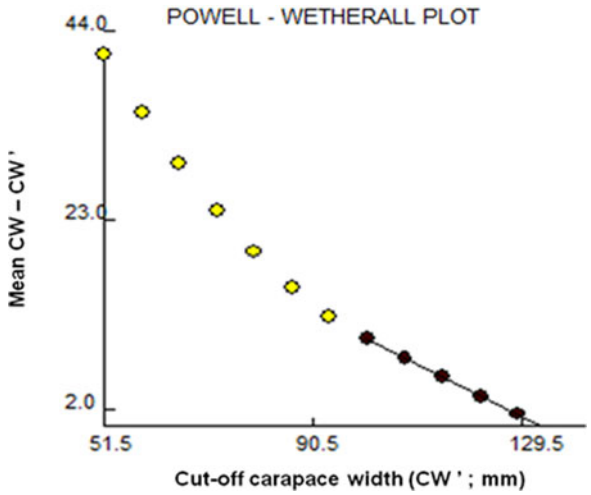

Fig. 6. Powell-Wetherall plot of female crabs.

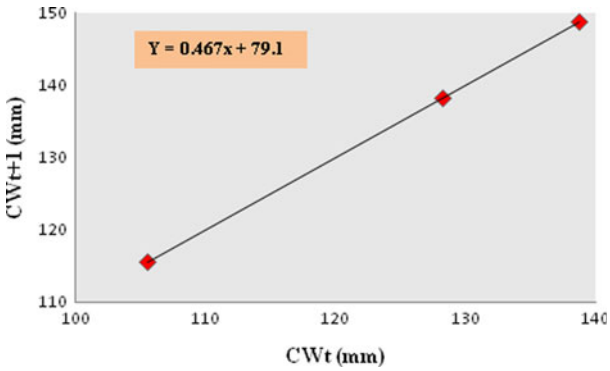

Fig. 7. Ford-Walford plot for male crabs.

results revealed that significant difference was observed in the exponent values (slope 'b') for both sexes ($P < 0.05$).

Age and growth

The estimated growth parameters such as CW_∞ and K derived through various methods are summarized in Table 1 and are presented in Figures 3–14. No significant difference was observed in the asymptotic carapace width (CW_∞) obtained through various methods in both sexes. In the case of the growth coefficient (K), the values ranged between 0.762–2.310 year^{-1}. The t_o values acquired through von Bertalanffy plot for male and female were found to be −0.637 and −0.681, respectively. The monthly distributions of mean modal lengths (the Gaussian components) derived by Bhattacharya and NORMSEP analysis are presented in Tables 2 and 3.

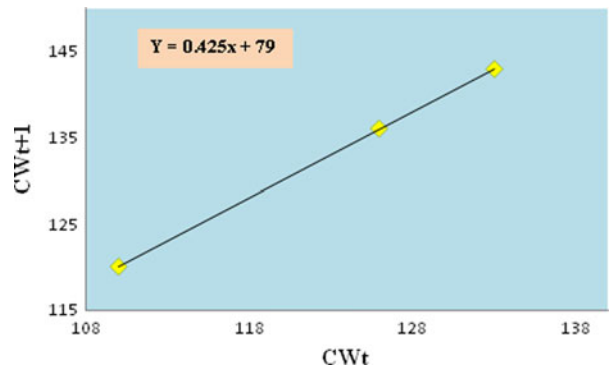

Fig. 8. Ford-Walford plot for female crabs.

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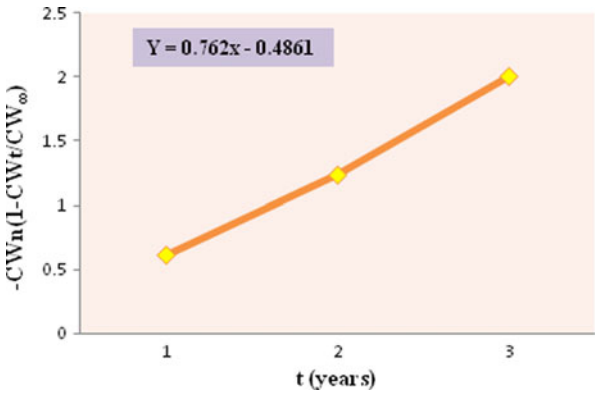

Fig. 9. von Bertalanffy plot for male crabs.

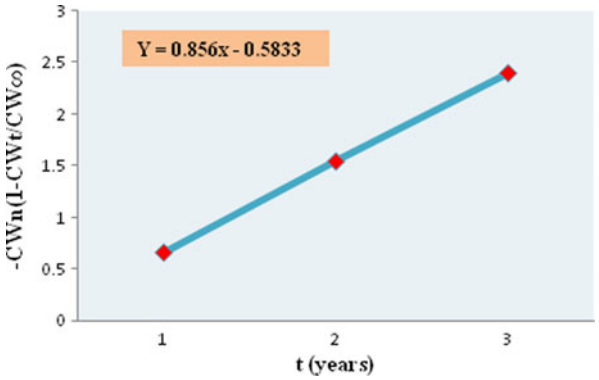

Fig. 10. von Bertalanffy plot for female crabs.

Around 46 components were resolved in Bhattacharya analysis for males, whereas in females 50 components are resolved. There exists a slight variation in Gaussian components between Bhattacharya and NORMSEP analysis. The results of decomposition of normal distribution by NORMSEP were plotted by taking sampling dates in the x-axis and mean lengths in the y-axis. The mean lengths which were believed to belong to the same cohorts were linked and as a result

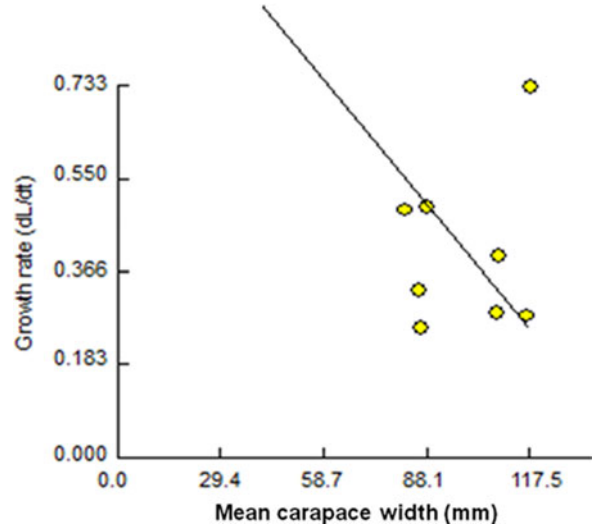

Fig. 11. Gulland and Holt plot for male crabs.

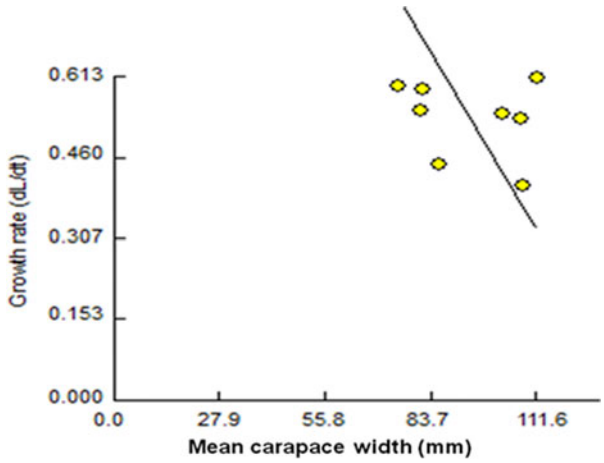

Fig. 12. Gulland and Holt plot for female crabs.

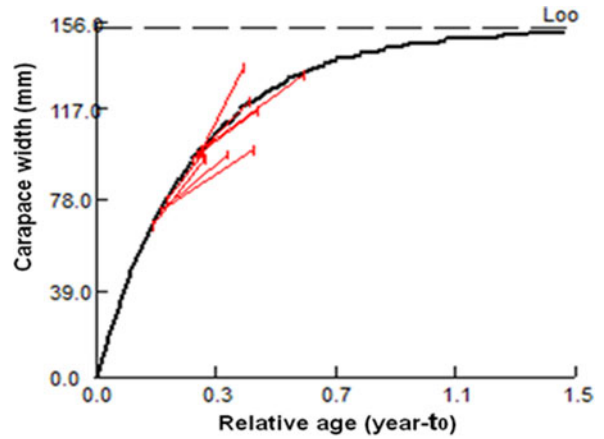

Fig. 13. Munro's plot for male crabs.

growth increment and carapace width at age (CW_t) files were created (Figures 15 and 16). The estimated growth performance index for male and females were found to be 4.222 and 3.911 respectively. The estimated longevity for male and female *S. olivacea* using different K values derived by different methods is given in Table 4.

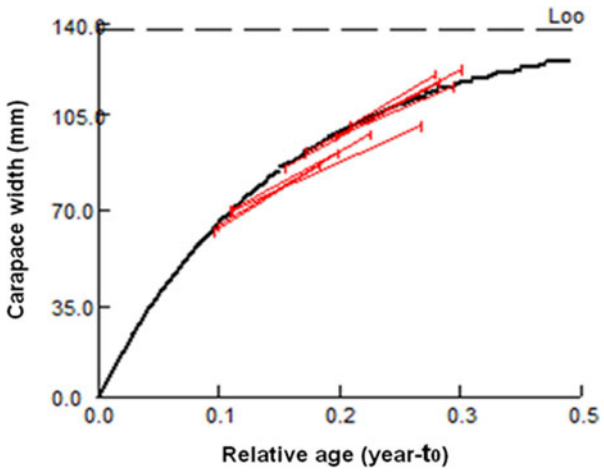

Fig. 14. Munro's plot for female crabs.

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Table 2. Gaussian components as mean modal lengths (mm) derived through Bhattacharya analysis for *S. olivacea*.

Month	First component		Second component		Third component	
	♂	♀	♂	♀	♂	♀
June 2010	85.54	93.88	111.64	121.28	138.27	–
July	77.55	93.01	108.25	120.35	–	–
August	76.37	77.33	100.67	97.56	–	117.74
September	83.68	92.36	113.14	117.73	–	–
October	75.99	104.31	109.07	122.73	–	–
November	86.42	91.12	132.54	116.51	–	–
December	86.93	93.50	112.03	117.61	–	–
January 2011	76.52	88.57	109.81	114.90	–	–
February	70.19	85.32	96.06	110.47	–	–
March	85.66	86.48	109.93	113.93	131.38	–
April	87.57	111.00	111.41	–	–	–
May	98.84	93.81	124.39	112.70	–	–
June	67.84	93.50	108.36	106.85	–	–
July	75.68	97.00	106.43	125.79	–	–
August	89.00	83.59	–	115.50	–	–
September	77.95	82.07	102.80	100.81	–	114.50
October	92.84	94.86	–	–	–	–
November	86.49	94.00	–	109.79	–	–
December	99.58	104.72	121.00	114.20	–	–
January 2012	88.22	99.30	115.76	117.31	–	–
February	111.55	89.22	–	113.11	–	–
March	101.67	101.24	127.85	114.50	–	–
April	91.48	68.82	131.32	93.97	–	119.70
May	107.50	72.50	130.69	99.23	–	120.14

DISCUSSION

There is little knowledge on carapace width-weight relationship and age and growth of *Scylla olivacea* because the available literature is very scanty. The results of the CWRs showed that *S. olivacea* collected from the Pichavaram mangroves revealed a significant deviation from isometric growth in both males and females. The estimated exponential values for males and females were 3.035 and 2.903, respectively. These findings fall in agreement with the results of

Table 3. Gaussian components as mean modal lengths (mm) derived through NORMSEP analysis for *S. olivacea*.

Month	First component		Second component		Third component	
	♂	♀	♂	♀	♂	♀
June 2010	85.54	93.88	111.64	121.28	138.27	–
July	77.55	93.01	108.25	120.35	137.63	–
August	76.37	77.33	100.67	97.56	128.06	117.74
September	83.68	92.36	113.14	117.73	–	–
October	75.99	104.31	109.07	122.73	135.60	–
November	86.42	91.12	132.54	116.51	–	–
December	86.93	93.50	112.03	117.61	–	–
January 2011	76.52	88.57	109.81	114.90	–	–
February	70.19	85.32	96.06	110.47	119.18	–
March	85.66	86.48	109.93	113.93	131.38	–
April	87.57	111.00	114.41	–	–	–
May	98.84	93.81	124.39	112.70	–	–
June	67.84	93.50	108.36	106.85	–	–
July	75.68	97.00	106.43	125.79	–	–
August	89.00	83.59	–	115.50	–	–
September	77.95	82.07	102.80	100.81	112.92	114.50
October	92.84	94.86	–	–	–	–
November	86.49	94.00	–	109.79	–	–
December	99.58	104.72	121.00	114.20	–	–
January 2012	88.22	99.30	115.76	117.31	–	–
February	111.55	89.22	–	113.11	–	–
March	101.67	101.24	127.85	114.50	–	–
April	91.48	68.82	131.32	93.97	–	119.70
May	107.50	72.50	130.69	99.23	–	120.14

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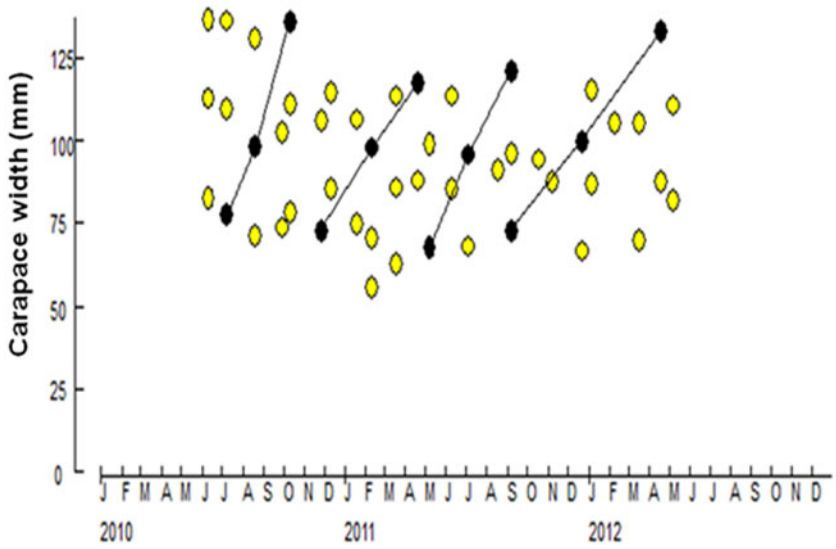

Fig. 15. Linking of means for male crabs.

Jirapunpipat (2008), who found values of 3.45 and 2.866 in males and females, respectively from the Klong Ngao mangrove swamp, Thailand. But Ikhwanuddin *et al.* (2010) observed low 'b' values such as 0.374 in males and 0.338 in females from Terengganu coastal waters, Malaysia. The results of the CWRs analysis in *S. olivacea* inferred that males are slightly heavier than females. The tendency of males to acquire heavier weight than females in portunids is in accordance with the observations of many authors (Prasad *et al.*, 1989; Sukumaran & Neelakantan, 1997; Razek *et al.*, 2006; Babu *et al.*, 2007; Josileen, 2011).

In the present study, the growth parameters CW_{∞} and K values raised through different methods are comparable and these were above the maximum length (L_{max}) values of 145 mm for males and 137 mm for females. There are very few investigations of the age and growth of *Scylla* spp. from Indian waters and hence the present results attain greater significance. The results of the present study found that females grew faster compared with males and it does not mean that females attain the CW_{∞} length faster than males. This trend was equally evinced by Lalitha Devi (1985) who found females growing faster (10 mm month^{-1}) than males (7 mm month^{-1}) in *S. serrata* from Kakinada region, east coast of India. Mark-recapture studies suggested that the growth rates of *S. olivacea* are much slower and were around 10 mm CW month^{-1} in Thailand (Moser *et al.*, 2002). A similar type of result was observed by Walton *et al.* (2006) from Vietnam and Philippines. Moser *et al.* (2002) noticed different growth rates in individuals of cohorts where some exhibit fast growth while others show slow growth. In general, the increment in carapace width of crustaceans varied between individuals undergoing the same moult (Hartnoll & Abele, 1982). The inter-moult duration increases as the age increases, particularly after sexual maturity, thus the rate of moult increment was higher in smaller crabs (Marichamy *et al.*, 1980; Kodama *et al.*, 2005).

The nature of crustacean growth by moulting has led to much difficulty in determining the true growth rate under natural conditions (Zafar *et al.*, 2006). Growth parameters vary in the same species, and might depend on habitat,

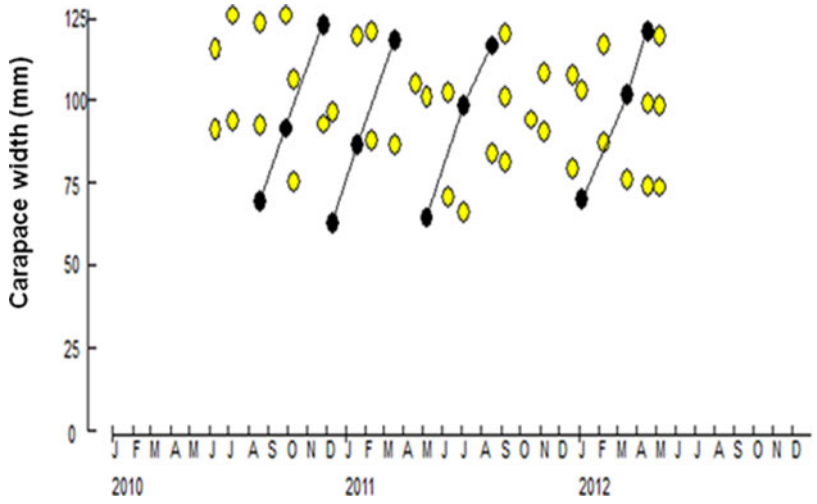

Fig. 16. Linking of means for female crabs.

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Table 4. Estimated longevity for males and females of *S. olivacea*.

Method	Males		Females	
	K value	Longevity (years)	K value	Longevity (years)
ELEFAN I	1.20	2.5	1.40	2.1
von Bertalanffy plot	0.76	3.9	0.85	3.5

environmental factors such as availability of food, temperature, salinity and feeding nature of the species and also disease caused by parasites; these play a crucial role in the growth rate. As age and growth studies in crabs are chiefly done indirectly, employing mathematical and statistical methods, a single method cannot be relied upon for conclusions because each method has its own merits, demerits and limitations. In view of these, the present investigation of the age and growth of *S. olivacea* was assessed through various methods in such a way that the outcome of one method acts as a rider, check and control over the other.

The present study assumes greater significance in view of the fact that no attempt has so far been carried out to explain CWRs and age and growth of *S. olivacea* from Indian waters. The outcome of the study will stand as a steady reference for future works aiming at determining the growth, according to sex, spawning season, estimating the population size of stock for exploitation purposes and implementation of responsible fishing for sustainable utilization of mud crabs.

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REFERENCES

Angell C.A. (1992) Summary of the proceedings of the seminar on mud crab culture and trade. In Angell C.A. (eds) *Seminar on mud crab culture and trade, Bay of Bengal programme*. Madras: BOBP Report, pp. 1–2.

Babu A.P., Sreedhara B. and Muniyappa Y. (2007) Fishery and stock assessment of *Portunus sanguinolentus* (Herbst) from south Karnataka coast, India. *Journal of the Marine Biological Association of India* 49, 134–140.

Bal D.V. and Rao K.V. (1984) *Marine fisheries*. New Delhi: Tata McGraw-Hill Publishing Company.

Hartnoll R.G. (2001) Growth in Crustacea – twenty years on. *Hydrobiology* 449, 111–122.

Hartnoll R.G. and Abele L.G. (1982) *The biology of crustacean embryology, morphology and genetics: Vol. 2*. New York, NY: Academic Press, pp. 111–196.

Ikhwanuddin M., Bachok Z., Hilmi M.G., Azmie G. and Zakaria M.Z. (2010) Species diversity, carapace width-body weight relationship, size distribution and sex ratio of mud crab, genus *Scylla* from Setiu wetlands of Terengganu coastal waters. *Malaysian Journal of Sustainable Science Management* 5, 97–109.

Jirapunpipat K. (2008) Population structure and size at maturity of the orange mud crab *Scylla olivacea* in Klong Ngao Mangrove Swamp, Ranong Province, Thailand. *Kasetsart Journal of Natural Science* 42, 31–40.

Josileen J. (2011) Food and feeding of the blue swimmer crab, *Portunus pelagicus* (Linnaeus, 1758) (Decapoda, Brachyura) along the coast of Mandapam, Tamilnadu, India. *Crustaceana* 84, 1169–1180.

Keenan C.P. (1999) Aquaculture of the mud crab, genus *Scylla* – past, present and future. In Keenan C.P. and Blackshaw A. (eds) *Mud crab aquaculture and biology*. ACIAR Proceedings No. 78. Canberra: Australian Centre for International Agricultural Research, pp. 9–13.

Keenan C.P., Davie P.J.F. and Mann D.L. (1998) A revision of the genus *Scylla* de Haan, 1833 (Crustacea: Decapoda: Brachyura: Portunidae). *Raffles Bulletin of Zoology* 46, 217–245.

Kodama K., Yamakawa T., Shimizu T. and Aoki I. (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, 141–150.

Lalitha Devi S. (1985) The fishery and biology of crabs of Kakinada region. *Indian Journal of Fisheries* 32, 18–32.

Le Cren E.D. (1951) The length–weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *Journal of Animal Ecology* 20, 201–219.

Le Vay L., Ut V.N. and Walton M. (2007) Population ecology of the mud crab *Scylla paramamosain* (Estampador) in an estuarine mangrove system; a mark-recapture study. *Marine Biology* 151, 1127–1135.

MacNae W. (1968) A general account of the fauna and flora of mangrove swamps and forests in the Indo-West Pacific region. *Advanced Marine Biology* 6, 73–270.

Marichamy R., Shanmugan S. and Rajapackiam S. (1980) Polyculture experiment in coastal water at Tuticorin. *Proceedings of Seminar on Coastal and Inland Fish Culture*. Tuticorin: Tamil Nadu Fisheries College, Tamil Nadu Agricultural University, pp. 241–251.

Maxwell K.E., Matthews T.R., Sheehy M.R.J., Bertelsen R.D., and Derby C.D. (2007) Neurolipofuscin is a measure of age in *Panulirus argus*, the Caribbean spiny lobster, in Florida. *Biological Bulletin* 213, 55–66.

Mirera O.D. (2011) Trends in exploitation, development and management of artisanal mud crab (*Scylla serrata*-Forsskal-1775) fishery and small-scale culture in Kenya: an overview. *Ocean Coastal Management* 54, 844–855.

Moser S., Macintosh D.J., Pripanapong S. and Tongdee T. (2002) Estimated growth of the mud crab *Scylla olivacea* in the Ranong mangrove ecosystem, Thailand, based on a tagging and recapture study. *Marine and Freshwater Research* 53, 1083–1089.

Pauly D. and David N. (1981) ELEFAN 1, a BASIC program for the objective extraction of growth parameters from length-frequency data. *Meeresforschung* 28, 205–211.

Prasad P.N., Reeby J., Kusuma N. and Neelakantan B. (1989) Width-weight and length-weight relationships in three Portunid crab species. *Uttar Pradesh Journal of Zoology* 9, 116–120.

Razek F.A., Taha S.M. and Ameran A.A. (2006) Population biology of the edible crab *Portunus pelagicus* (Linnaeus) from Bardawil Lagoon, Northern Sinai, Egypt. *Egyptian Journal of Aquatic Research* 32, 401–418.

https://doi.org/10.1017/S0025315415001216 Published online by Cambridge University Press

Sekharan K.V. (1962) On the oil sardine fishery at the Calicut area during the years 1955–56 to 1958–59. *Indian Journal of Fisheries* 9A, 679–700.

Sukumaran K.K. and Neelakantan B. (1997) Food and feeding of *Portunus* (*Portunus*) *sanguinolentus* (Herbst) and *Portunus* (*Portunus*) *pelagicus* (Linnaeus) (Brachyura: Portunidae) along the Karnataka coast. *Indian Journal of Marine Science* 26, 35–38.

Viswanathan C., Elumalai V., Pravinkumar M. and Raffi S.M. (2012) DNA barcoding and first report on the confirmation of mud crab *Scylla olivacea* (Brachyura: Portunidae) availability in East coast of India. *Journal of Environmental and Applied Bioresearch* 1, 1–4.

Vogt G. (2011) Ageing and longevity in the Decapoda (Crustacea): a review. *Zoologischer Anzeiger* 251, 1–25.

Walton M.E., Le Vay L., Lebata J.H., Binas J. and Primavera J.H. (2006) Seasonal abundance, distribution and recruitment of mud crabs (*Scylla* spp.) in replanted mangroves. *Estuarine, Coastal and Shelf Science* 66, 493–500.

and

Zafar M., Amin S.M.N. and Rahman M.M. (2006) Population dynamics of mud crab (*Scylla serrata*) in the southern coastal region of Bangladesh. *Asian Fisheries Science* 19, 43–50.

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