Fishery and stock assessment of the three-spot swimming crab *Portunus sanguinolentus* (Herbst, 1783) off Veraval, Gujarat

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ABSTRACT

The fishery and stock characteristics of *Portunus sanguinolentus* was studied during 2009-2010 from Veraval waters. The average annual landing was 322 t, which constituted about 40% of the total edible crab landings at Veraval. Length-weight relationship showed isometric growth. L_∞, K and t_0 estimated were 178.7 mm, 1.2 yr^{-1} and -0.08 yr, respectively. Total mortality rate (Z), fishing mortality rate (F) and natural mortality rate (M) were estimated to be 4.69 yr^{-1}, 2.85 yr^{-1} and 1.84 yr^{-1}, respectively. The estimated length at capture (L_{50}) and length at maturity (LM_{50}) were 101.33 mm and 96.89 mm, respectively, indicating that the crabs enter into peak exploitation phase after attaining sexual maturity. The species is a continuous spawner and shows peak recruitment during May and August. The current exploitation rate (E_{cur}) was found to be 0.61 which is equal to $E_{0.1}$ estimated by Beverton and Holt yield per recruit analysis. Thompson and Bell bio-economic analysis showed that species can be exploited at the present level to maintain the revenue from the fishery at economic level.

Keywords: *Portunus sanguinolentus*, Size at maturity, Spawning stock biomass, Stock assessment

Introduction

Marine crabs are one of the valuable crustacean resources of India having very good domestic as well as international market demand. Though about 600 species of crabs have been recorded from Indian waters, only few species are consumed (Rao *et al.*, 1973). The fishery of edible crabs in India is sustained mainly by crabs of the family Portunidae. The three-spot swimming crab, *Portunus sanguinolentus* (Herbst, 1783) is widely distributed in ocean waters from east Africa, through the Indo-Pacific region, to the Hawaiian Islands (Stephenson and Campbell, 1959). Other major species in the fishery include *Charybdis feriata*, and *Portunus pelagicus*. Exploitation of crabs in Gujarat was at a subsistence scale till late nineties and were mainly exploited by traditional gears like traps, fence net, umbrella net, drag net, spears *etc*. Diminishing marine fish production and increasing demand for sea foods in domestic as well as international markets brought remarkable changes in utilisation pattern of catch and by-catch of trawls. Crabs are one of the non-commercial group which benefited greatly by this change and since then a small scale fishery for crabs has been continuing in the state, where the resource is mainly being exploited by trawl nets and gill nets (Kizhakudan, 2002). In Veraval, crabs are not a targeted fishery resource and are mainly landed as by-catch of trawling. The crabs are sorted and inedible species as well as very small sizes are usually discarded, due to which the estimation of actual catch and juvenile discard becomes difficult. Moreover, most of the crabs are landed in a putrefied state and can be used only for fish meal production. *P. sanguinolentus* contributes about 40% of the edible crab landing at Veraval. Though considerable information on fishery and population dynamics of crabs have been reported from both west and east coasts of India (Rao *et al.*, 1973; Lalitha Devi, 1985; Telang and Tippeswamy, 1986; Sukumaran and Neelakantan, 1996 a, b, c, 1997 a, b, c; Dineshbabu *et al.*, 2007; Jose and Menon, 2007; Dineshbabu, 2011, Pillai and Thirumilu, 2012), there is a dearth of information on the biology and population dynamics of *P. sanguinolentus* from north-west coast of India. Hence, the present study was conducted to investigate the stock characteristics of *P. sanguinolentus* from Veraval waters of Gujarat, so that management measures can be suggested to sustain the fishery.

Materials and methods

Data on catch, effort and size composition were collected fortnightly for a period of two years from January 2009 to December 2010 from commercial trawlers of Veraval Fishing Harbor, Gujarat. Catch and effort data available at the Regional Centre of the Central Marine Fisheries Research Institute at Veraval, for the period 2006-2008 were also used for the study. Individual carapace width (CW) (*i.e.* length between tips of the longest lateral spines across the middle line between the

frontal notch and the posterior margin) and the individual body weight were recorded to the nearest millimeter (mm) and milligram (mg). A total of 1399 fresh specimens of *P. sanguinolentus* in the size range of 70-175 mm (CW) were sampled for the study. The CW composition data were raised to the monthly catch estimated by Fisheries Resources Assessment Division of CMFRI. The von Bertalanffy's growth parameters *viz.*, asymptotic length (L_∞) and growth co-efficient (K) were estimated using the ELEFAN 1 module of FiSAT II (Gayanillo *et al.*, 2005). Age at length zero (t_0) was calculated using empirical formula: $Log_{10} (-t_0) = -0.3922 - 0.2752 \log_{10} L_\infty - 1.038 \log_{10} K$ (Pauly, 1979). Growth performance index (φ) was calculated from formula: $\varphi = \log_{10} K + 2\log_{10} L_\infty$ (Pauly and Munro, 1984). Longevity was estimated from the equation: $t_{max} = 3/K + t_0$ (Pauly, 1983a). The CW-weight relationship of *P. sanguinolentus* was established following the formula, $W = aL^b$ (Le Cren, 1951).

The instantaneous total mortality rate (Z) was estimated by FiSAT II package using the length converted catch curve method (Pauly, 1983b). Considering the bottom dwelling nature of the crab and sub-tropical climatic condition of the environment, the natural mortality rate (M) was estimated by Srinath's empirical formula: M=1.535 K (Srinath, 1998), and the fishing mortality rate (F) was obtained as F= Z-M. The current exploitation rate (E_{cur}) was calculated as E= F/Z (Ricker, 1975). Length structured virtual population analysis (VPA) of FiSAT II was used to obtain fishing mortalities per length class.

For determining length at maturity (LM_{50}) *i.e.,* length at which 50% of the crabs in stock become mature, 787 females of 70 to 174 mm CW collected between January 2009 and December 2010 were used for the analysis. Maturity stage of the females were determined by the size and color of ovary and classified into 6 stages *viz.,* stage-1: immature virgin (thread like colourless ovary), stage-2: immature resting (thick and translucent or yellow or brown orange colour ovary), stage-3: early maturing (slightly enlarged and ivory to yellow colour ovary), stage-4: late maturing (swollen with pronounced lobules and yellow to orange colour ovary), stage-5: mature (greatly swollen and deep orange colour ovary) and stage-6: spent (flaccid and ivory to yellow orange colour ovary) (Sukumaran and Neelakantan, 1998) and the proportions of mature female (stage-5 and above) in sequential length classes (5 mm) were used for the logistic regression analysis as described by Ashton (1972) : $P = e^{a+b(CW)} / 1 + e^{a+b(CW)}$ where P is the predicted mature proportion, *a* and *b* the estimated coefficients of the logistic equation and CW the carapace width. Size at first maturity was estimated as the negative ratio of the coefficients (-a/b).

The recruitment pattern of the stock was determined by backward projection on the length axis of the set of available length frequency data as described in FiSAT II. Temporal spread was reduced by using the restructured data and normal distribution of the recruitment pattern was determined by maximum likelihood method using NORMSEP (Pauly and Caddy, 1985).

The midpoint of the smallest length group in the catch during the five-year period was taken as length at recruitment (Lr). Length at capture (L_{50}) *i.e.*, the carapace width at which 50% of the crabs in stock become vulnerable to gear was estimated by probability of capture routine in the FiSAT-II package. The probability of capture was approximated by backward extrapolation of the regression line of descending limb of length converted catch curve (Pauly, 1987). The probability of capture of sequential length classes were regressed using a logit curve for the estimation of L_{50}.

Since both male and female crabs share the same fishing ground and are exposed to same fishing method, it is impracticable to manage the fishery separately and hence the pooled data was used for stock assessment study. The relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) at different fishing levels were estimated by FiSAT II package using relative yield per recruit analysis method (Beverton and Holt, 1966). The economic yield (Y), total biomass (B) and spawning stock biomass (SSB) at different fishing levels were predicted using length based Thompson and Bell bio-economic model (Thompson and Bell, 1934).

## Results and discussion

Fishery and seasonal abundance

The annual catch data of *P. sanguinolentus* during 2006-2010 (Table1) reveals that the monthly catch and catch rate remained more or less same throughout the period with an average catch of 322 t per annum and catch rate (CPUE) of 6.3 kg per unit. The average monthly catch was highest during March and April followed by October, and the highest monthly CPUE was observed during May followed by March and April which indicates that the peak fishing season for the species is March and April followed by October (Fig. 1).

Stock structure

Of the 1,399 individuals studied, males constituted 43.75% (n=612) and females constituted 56.25% (n=787) with an overall sex ratio of 1.3. The mean CW of male populations (118.76 mm) was found to be significantly higher than female population (114.84 mm) (independent t-test, p ≤ 0.01) indicating that the stock is composed of

Table 1. Trawl effort and catch of *P. sanguinolentus* landed at Veraval during 2006 to 2010

Year	Efforts (units)	Total trawl landing (t)	Total commercial crab landing (t)	*P. sanguinolentus*		
				Catch (t)	CPUE (kg U^{-1})	% to total edible crab landing
2006	51510	118525	857	339	6.6	39.6
2007	45383	92811	402	163	3.6	40.4
2008	54080	140774	876	374	6.9	42.7
2009	51551	129790	854	323	6.3	37.9
2010	51107	150115	1044	412	8.1	39.5
Average	50726	126403	807	322	6.3	40.0
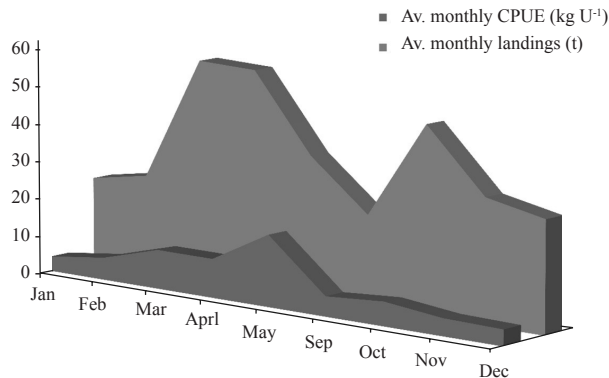
Fig. 1. Seasonal abundance of *P. sanguinolentus* at Veraval during 2006-2010

larger sized males compared to females and dominated by female individuals in number. The mean and mode CW of pooled data was found to be 116.58 mm and 122.5 mm, respectively (Fig. 2). In the present study, deviation of the stock structure from normal distribution could be due to limitations in the sampling where discarded crabs were not included. Moreover, crabs have a typical biological behaviour of aggregating in specific areas particularly during breeding seasons with differential grouping among sizes (Kizhakudan, 2002) which possibly influences the size composition within samples.

Growth, mortality and exploitation parameters

Growth, mortality and exploitation parameters obtained in the present study are given in Table 2. The L_∞ (181 mm for female and 174.2 mm for male) and K (1.1 yr^{-1} for female and 1.4 yr^{-1} for male) obtained in the present study are comparable with earlier studies (Table 3). Since estimation of growth parameters by ELEFAN is greatly influenced by population structure and sampling bias/limitations, the L_{max} (maximum length in sample) can vary from location to location for the same species. However, growth performance index (φ) obtained in the present study (female 2.55 and male 2.62) was found to be in the reasonable range (2<φ<3) within the same family (Pauly and Munro, 1984). The restructured CW data and growth parameters of pooled data are given in Fig. 3 using which, it was estimated that the crab attains 129.83 mm CW at the end of 1st year, 163.98 mm CW at the end of the
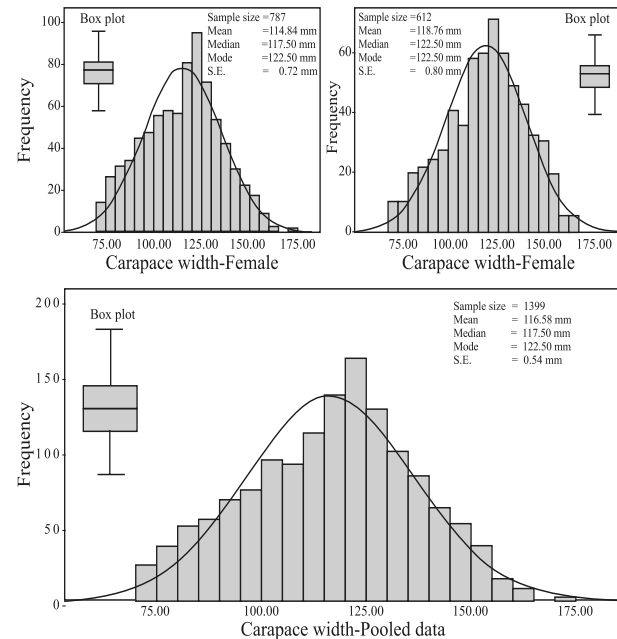
Fig. 2. Stock structure of *P. sanguinolentus* at Veraval during 2009-2010

2nd year and 174.27 mm CW at the end of 3rd year. The growth rate (K) and performance (φ) of male in the present study was found to be higher than female. As males are not physiologically associated with egg production and incubation, they save energy for somatic growth and show higher growth rate (Hartnoll, 1982). The longevity (t_{max}) obtained in the present study was 2.42 yr which is comparable to earlier reports (Dineshbabu *et al*., 2007).

The M was found to be higher in males compared to females whereas, the Z, F and E_{cur} were found to be lower in males compared to female (Table 2, Fig. 4). The F (2.8 yr^{-1}) observed in the present study, was higher than M (1.84 yr^{-1}) as a result of which E_{cur} (0.61) was found to be higher than the optimum exploitation rate (0.5) as reported by Gulland (1971). Virtual population analysis showed that F exceeded M when the crabs attain 120 mm CW. The maximum fishing mortality (3.06 yr^{-1}) was observed at the CW of 150-155 mm (Fig. 5).
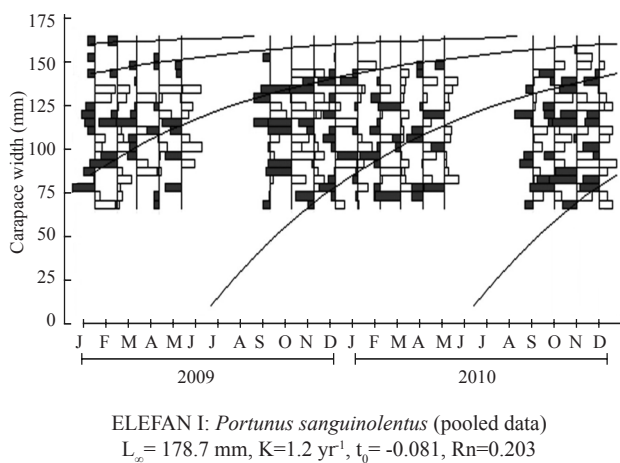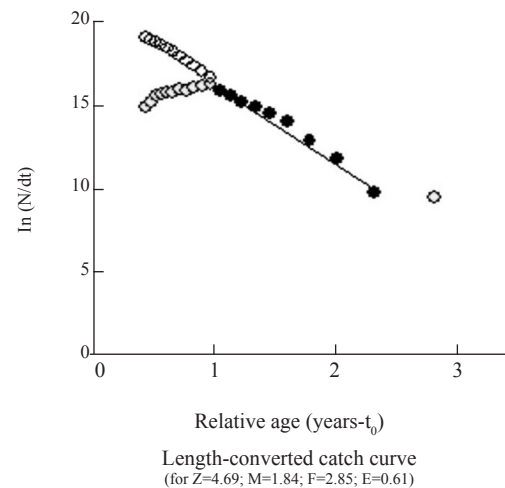
Table 2. Stock parameters of *P. sanguinolentus* from Veraval waters during 2009 - 2010

Sex	von Bertalanffy's growth parameters			Growth performance index	Mortality rates			Exploitation rate (E_{cu})
	L_∞(mm)	K (yr^{-1})	t_0 (yr)	(φ)	M (yr^{-1})	Z (yr^{-1})	F (yr^{-1})	
Male	174.2	1.4	-0.07	2.62	2.15	4.19	2.04	0.49
Female	181.0	1.1	-0.09	2.55	1.69	4.44	2.75	0.62
Pooled	178.72	1.2	-0.08	2.59	1.84	4.69	2.85	0.61

Table 3. Stock parameters of *P. sanguinolentus* from earlier studies

Authors and place of study	Growth parameters					
	L_∞ (mm)		K (yr^{-1})		L_{max} (mm)	
	Male	Female	Male	Female	Male	Female
Sukumaran and Neelakantan (1997 b); south-west coast of India	195.0	188.0	0.99	0.82	169	166
Sarada (1998), Calicut waters	172.9	161.8	1.5	1.6	175	155
Lee and Hsu (2003), Taiwan waters	204.8	194.3	0.87	0.97	193	182
Dineshbabu *et al*. (2007); Karnataka waters	169.0	170	1.6	1.6	170	160
Pillai and Thirumilu (2012); Chennai waters	161.8	168.6	1.1	1.3	155	165

Authors and place of study	Mortality parameters					
	M (yr^{-1})		F (yr^{-1})		Z (yr^{-1})	
	Male	Female	Male	Female	Male	Female
Sukumaran and Neelakantan (1996c); south-west coast of India	1.6	2.4	2.6	1.5	4.2	3.9
Lee and Hsu (2003); Taiwan waters	1.65	1.8	1.51	1.57	3.16	3.37
Dineshbabu *et al*. (2007); Karnataka waters	2.80	2.80	3.2	4.0	5.96	6.84
Pillai and Thirumilu (2012); Chennai waters	1.1	1.2	2.1	3.0	3.2	4.3

ELEFAN I: *Portunus sanguinolentus* (pooled data)
L_∞ = 178.7 mm, K=1.2 yr^{-1}, t_0= -0.081, Rn=0.203

Fig. 3**.** Restructured growth curve of *P. sanguinolentus* for 2009 to 2010

Length-converted catch curve
(for Z=4.69; M=1.84; F=2.85; E=0.61)

Fig. 4. Estimation of Z of *P. sanguinolentus* from length converted catch curve method.
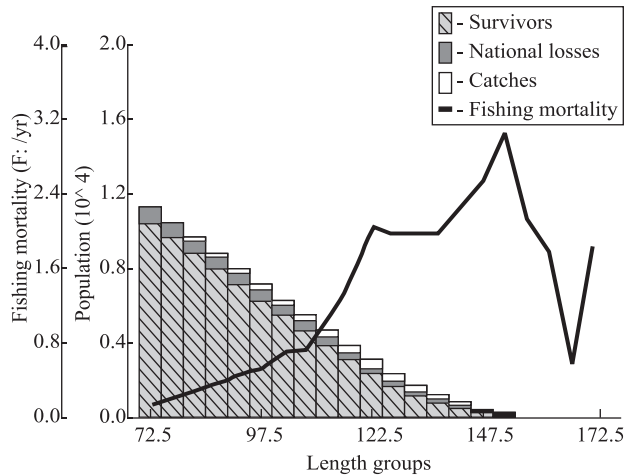
Fig. 5. Length structured VPA for *P. sanguinolentus* for the years 2009-2010

Fig. 6. Carapace width and body weight relationship of *P. sanguinolentus* (pooled data)

Length-weight relationship

The relationship between carapace width and body weight for different groups (male, female and pooled data) were derived as:

Male   : W= 0.000042 CW $^{3.09}$ (r^2=0.96, n=612)

Female: W= 0.000033 CW $^{3.10}$ (r^2=0.95, n=787)

Pooled : W= 0.000042 CW $^{3.06}$ (r^2=0.94, n=1399)

where W is weight in g and CW is carapace width in mm. Analysis of covariance test revealed that the intercept of male was significantly higher than the female (p≤0.05). The relationship between CW-body weight for the pooled data indicates that though growth is isometric, males are comparatively heavier than females of same length (Fig. 6). This concurs with earlier findings where males were found to be heavier than females (Sukumaran and Neelakantan, 1997a; Dineshbabu *et al.*, 2007). According to an earlier morphometric study, it has been found that chela length of male is significantly higher than female of same CW (Hsu *et al.*, 2000) which could be attributed as a reason for heaviness of males.

Maturity, recruitment and gear selectivity

The Lm_{50} for *P. sanguinolentus* was found to be 96.89 mm CW (Fig. 7) and the same length was attained in 0.65 yr (8th month). The Lm_{50} in the present study was found to be higher; than the earlier reports (Lalitha Devi, 1985; Sarada 1998; Dineshbabu *et al.*, 2007; Pillai and Thirumilu, 2012). Brachyuran crabs show significant variation in Lm_{50} depending on the geographical location (Hines, 1989). Environmental factors such as water temperature and salinity which varies from location to location can also affect Lm_{50} (Fisher, 1999). In the present study, berried females were recorded throughout
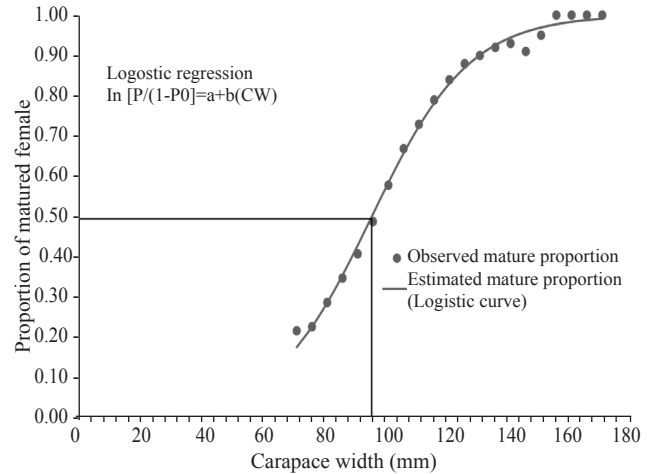
the entire fishing period which indicates that the species is a continuous spawner. Unlike temperate waters, the brachyuran crabs inhabiting tropical waters usually breeds throughout the year (Warner, 1977). Since highest percentage of mature and berried females was observed during March to May, the same period can be assumed as peak spawning period, as suggested by Rasheed and Mustaquim (2010). The Lr for *P. sanguinolentus* was found to be 72.5 mm. The recruitment pattern demonstrated that young crabs were recruited in the fishery continuously throughout the year with two peaks, first peak in May (8%) followed by second peak in August (24%) (Fig. 8). Higher recruitment peak in August coincides with peak spawning during March to May. The L_{50} for *P. sanguinolentus* was found to be 101.33 mm which is higher than Lm_{50}. This indicates that crabs enter into peak exploitation phase after attaining sexual maturity (Fig. 9).

Stock assessment

"Selection ogive" was used for the relative yield per recruitment analysis of *P. sanguinolentus* as "knife edge selection" could lead to substantive bias in the analysis for short lived, fast growing tropical species (Pauly and Soriano, 1986; Silvestre *et al.*, 1991; Silvestre and Garces, 2004). The analysis showed that maximum Y/R could be obtained at E_{max} of 0.75 suggesting scope for increase in exploitation rate (Fig. 10). However, the results should be carefully evaluated since the analysis does not consider the spawning stock biomass which is essential for maintaining the recruitment in the future (Clark, 1991) and E_{max} usually corresponds to very low levels of B/R. Moreover, *P. sanguinolentus* is a small, fast growing and typically r-selected species which is characterised by higher natural mortality (Gunderson, 1980; Lee and Hsu, 2003) and for such species the E_{max} may be unrealistically high
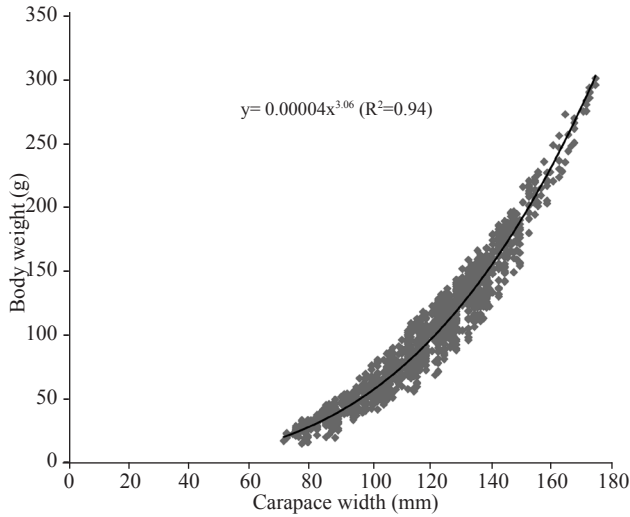
Fig. 7. Size at maturity (LM$_{50}$) of *P. sanguinolentus*
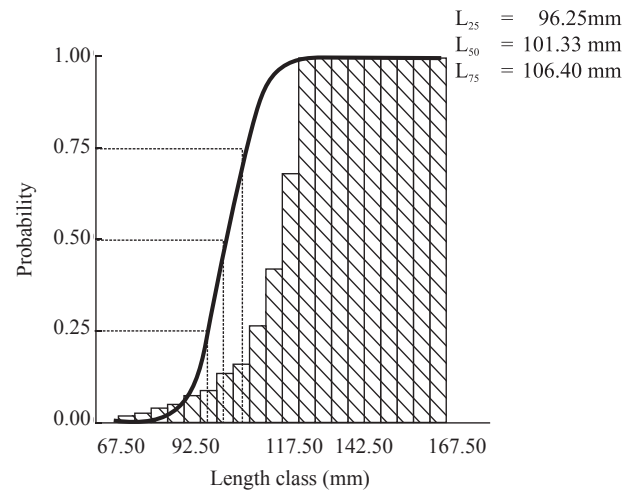

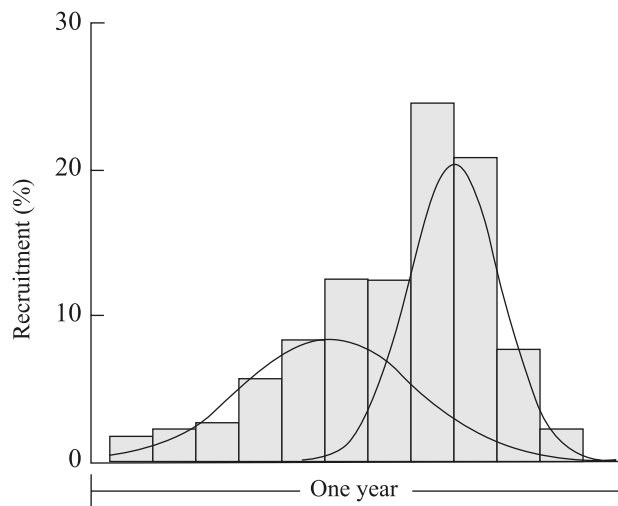Fig. 9. Length at capture (Lc$_{50}$) of *P. sanguinolentus*

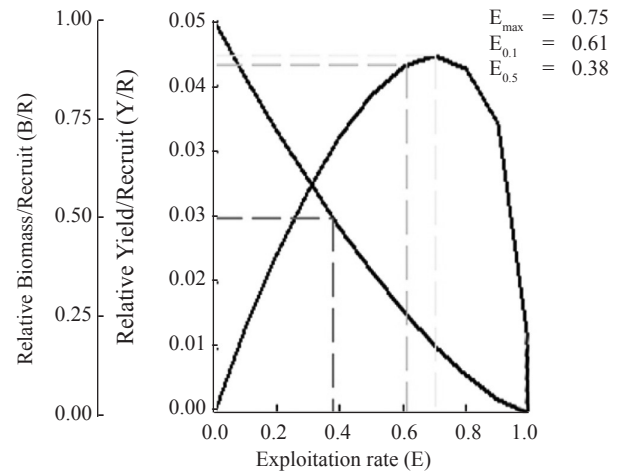Fig. 8. Recruitment pattern of *P. sanguinolentus*

Fig. 10. Relative yield per recruit analysis of *P. sanguinolentus*

(Gulland 1983; Pauly, 1984). Therefore, it is recommended that exploitation should be reduced to a precautionary level *i.e.*, E$_{0.1}$ (an effort level at which the marginal increase in yield per recruit reaches 1/10 of the marginal increase computed at a very low value of E). Therefore, E$_{max}$ and E$_{0.1}$ can be used as proxies for the maximum sustainable yield (MSY) and maximum economic yield (MEY), respectively and set as a target reference point (TRP) (Jakubaviciute *et al.*, 2011). In the present study, E$_{0.1}$ and E$_{cur}$ are same which indicates that the fishery is running at economic reference point (MEY).

E$_{0.5}$ represents exploitation rate at which B/R reduces by 50% compared to virgin stock, *i.e.,* to the level which theoretically maximises surplus production (Pauly, 1984)

and the same can be used as a proxy for the optimum sustainable yield (OSY) (Dadzie *et al.*, 2005). In the present study, the optimum biomass of *P. sanguinolentus* can be maintained at E$_{0.5}$ of 0.38 whereas, E$_{cur}$ is high and depleting the B/R considerably. Since B/R and E are proxies for catch rate (CPUE) and effort (F), respectively, it shows that the CPUE decreases with the increase in F. But this decrease in CPUE should not be confused with growth overfishing as the latter occurs at a very high fishing effort (usually above F$_{msy}$) where growth cannot balance the death process (Sparre and Venema, 1998). So far as recruitment overfishing is concerned, it is necessary to understand the relationship between spawning stock biomass (SSB) and recruitment. Since the relationship in the present crab fishery is unknown and we

are assuming constant recruitment over the period, it will be difficult to comment on recruitment overfishing.

Earlier studies have indicated that spawning stock biomass per recruit (SSBR) can be used as TRP and should be maintained at 20% for stocks having average resilience and at 30% for the little known stocks (Mace and Sissenwine, 1993). Due to the principle of uncertainty in stock assessment, it is advisable to use precautionary management reference points such as SSBR (20-30% of virgin stock) to prevent recruitment overfishing, even where relationship between spawning stock size and recruitment cannot be established statistically (Rosenberg and Repestro, 1996). Thompson and Bell bio-economic analysis (Fig. 11) shows that yield increases from 344.48 t (current equilibrium yield) to 389.60 t (MSY) as the fishing level (F-factor) increases to 2.8 times the present value after which yield decreases. However, the F_{msy} (7.98) reduces the SSB to about 19% of virgin spawning stock biomass (SSB_0), which could be detrimental for the long term sustainability of the stock. Similarly, the economy of the yield maximises from ₹ 23.22 million to ₹ 23.32 million as the fishing level (F-factor) increases up to 1.2 times the present value after which it decreases. But unlike F_{msy}, F_{mey} (3.42) is maintaining the SSB at about 35.33% of SSB_0, which is acceptable. However, the marginal increase in revenue (0.4%) due to 20% increase in effort is very less. Moreover, considering the multispecies nature of the fishery, an increase of 20% in effort could be detrimental to other fishery resources. Since the current fishing level maintains the SSB at about 40% of SSB_0 and B at about 46% of B_0, exploitation can be continued at the current rate.
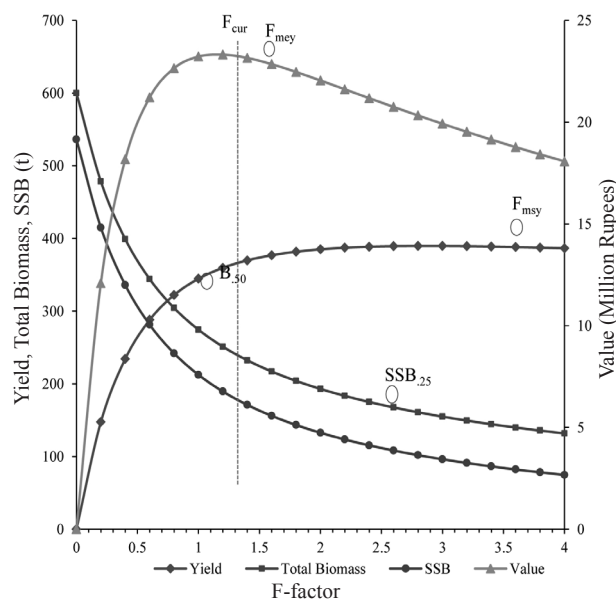
The inferences drawn in the present study are based on observations which may have certain drawbacks such as bias in size composition due to sampling limitations as well as biological behaviour of the crabs. This gives rise to the possible scope of uncertainty in assessing the stock status and in such cases, conclusions should be drawn following a precautionary approach giving due consideration to the biological nature of the species. In the present study, the species is an r-selected species which spawns all round the year and fishery is mainly targeting the mature crabs. Since, the E_{cur} for the species has already achieved the $E_{0.1}$ while maintaining the SSB at a precautionary safe level and revenue almost equal to MEY, exploitation can be continued at the present level for sustainable fishery.

Acknowledgements

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Fig. 11. Thompson and Bell analysis of *P. sanguinolentus*

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