Analysis of fishery and stock of the portunid crab, *Charybdis feriata* (Linnaeus, 1758) from Veraval waters, north-west coast of India

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ABSTRACT

Fishery and stock characteristics of the portunid cab *Charybdis feriata* from the waters off the north-west coast of India was studied based on commercial trawl landings at Veraval during 2009-2011. Growth parameters L_∞, K and t_0 were estimated as 171.5 mm, 0.97 yr^{-1} and -0.10 yr respectively. Mortality parameters Z, M and F were 3.97 yr^{-1}, 1.49 yr^{-1} and 2.48 yr^{-1} respectively. The length at capture (L_{50}) and length at maturity (L_{M50}) were 95.4 mm and 87.3 mm, respectively which indicates that crabs enter into peak exploitation phase after attaining sexual maturity. The bio-economic stock assessment model showed that the species can be exploited at the present fishing level to maintain the economy of the fishery at maximum level (MEY) or the effort can be increased by 2.4 times to maximise the yield (MSY) depending upon the management objective. However, since the stock recruitment relationship is not defined, as a precautionary approach, the effort should not be increased more than 1.3 times the present level to conserve the spawning stock.

Keywords: *Charybdis feriata*, Fisheries management, Management reference point, Spawning stock biomass, Stock assessment

Introduction

Stock assessment is the quantitative evaluation of status of exploited living resources and predictions about their responses to alternative management strategies using various statistical models. The analytical models are usually preferred than biomass production models as they provide comparatively reasonable estimation of stock parameters. Similarly, depending upon the management objective (socio-economical, commercial, biological, recreational and conservational), several reference points are used for the management of fishery resources. However, the accuracy of any management reference point is influenced by the level of understanding about stock characteristics such as growth parameters, mortality parameters and spawning stock-recruitment relationships. The crucifix crab, *Charybdis feriata* (Linnaeus, 1758) (Family: Portunidae) is widely distributed throughout the Indo-pacific region (Apel and Spiridonov, 1998; Ng, 1998; Abello and Hispano, 2006). It is a sub-littoral species and found in a wide range of substrata ranging from muddy to rocky bottom (Ng, 1998; Yan, *et al*., 2004) and is one of the important edible marine crab resources of India. Crabs are not targeted resources but are mainly landed as bycatch at Veraval of single day and multiday trawl operations along north-west coast of India targeting shrimp and other demersal fishery resources. They are often subjected to sorting onboard and sizes found unsuitable for human consumption are usually discarded at sea or when landed as inedible bycatch, used for fish meal production.

Though there are studies on the fishery (Lalithadevi, 1985; Padayatti, 1990), morphometrics, food and feeding behaviour (Rameshbabu *et al*., 2002a, b), reproductive biology (Padayatti, 1990; Rameshbabu *et al*., 2006) and population dynamics (Dineshbabu, 2011) of this crab from different parts of India, there is no earlier report about this resource from Gujarat. Therefore, the present study was conducted to assess the fishery and stock of *C. feriata* along this coast and to judge the possible implication of uncertainty involved in decision making so that precautionary approach can be suggested for sustainable exploitation of the resource.

Materials and methods

Data on catch, effort and size composition was collected fortnightly for a period of 3 years from January 2009 to December 2011 from commercial trawlers of Veraval Fishing Harbour, India (20°54' 0.50"N; 70°22' 9.60"E). Individual carapace width (CW) between tips of the longest lateral spines across the middle line between the frontal notch and the posterior margin was measured to the nearest mm using a digital caliper (Yamayo Measuring Tools Co. Ltd., Japan) and the individual body weight was recorded to the nearest gram using an electronic weighing machine (Scale-Tec™, India). A total of 1544 fresh specimens of *C. feriata* in the size range of 61-163 mm (CW) were collected randomly for analysis. The von Bertalanffy's growth parameters *viz*., asymptotic length (L_∞) and growth co-efficient (K) were estimated using monthly raised data in the ELEFAN 1 module of FiSAT II (Version 1.2.2) (Gayanillo *et al.*, 2005). Age at length zero (t_0) was calculated using 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: φ=log_{10} K+ 2log_{10} L_∞ (Pauly and Munro, 1984). Longevity was estimated from the equation: t_{max}=3/K + t_0 (Pauly, 1983a). The CW-weight relationship of *C. feriata* was established following the formula, W=aL^b (Le Cren, 1951) and similarity of regression lines were tested using analysis of covariance (ANCOVA) test.

The instantaneous total mortality rate (Z) was estimated by FiSAT II package using the length converted catch curve method (Pauly, 1983b). The natural mortality rate (M) was estimated using the 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.

The midpoint of the smallest length group in the catch during the three-year period was taken as length at recruitment (Lr). Length at capture *i.e.,* length at which 50% of the crabs in the stock becomes vulnerable to the gear (L_{50}) was estimated by probability of capture routine in the FiSAT-II package. For determining length at maturity (L_{M50}), females of *C. feriata* (CW=67-163 mm, n=640) collected during January 2009 to December 2011 were used. Maturity stage of the females were determined by the size of ovary and were classified into 5 stages *viz.*, stage-1: immature, stage-2: early maturing, stage-3: late maturing, stage-4: Mature, and stage-5: Spent (Ryan, 1967). Proportions of mature female (*i.e.,* crabs which have completed stage-3) in sequential length classes (5 mm) were used for the logistic regression analysis following the method described by Ashton (1972): $P = e^{a+b(CW)}/1+e^{a+b(CW)}$ where P = predicted mature proportion, a and b are the estimated coefficients of the logistic equation and CW = carapace width. L_{M50} was estimated as the negative ratio of the coefficients (-a/b).

Since both male and female crabs inhabit the same fishing ground and are exposed to fishing at the same time, without discrimination, it is impracticable to manage the fishery separately and hence the sex 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 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

The annual catch and effort data of *C. feriata* during 2009-2011 is shown in Table 1. An average landing of 541 t per annum was harvested with an average catch rate (CPUE) of 11 kg per boat. During this period, though the contribution of *C. feriata* to the fishery was negligible, it constituted 44% of the annual average edible crab landing. An increase in the annual catch and catch rate of *C. feriata* was observed during the study period (2009-2011).

Table 1. Trawl effort and catch of *C. feriata* landed at Veraval during 2009 to 2011

Year	Efforts (boats)	Total trawl landing (t)	Total commercial crab landing (t)	*Charybdis feriata*			
				Catch (t)	CPUE (kg boat⁻¹)	% to total crab landing	% to total trawl landing
2009	51551	129790	854	349	8	41	0.27
2010	51107	150115	1044	473	9	45	0.32
2011	53081	141433	1780	802	15	45	0.57
Average	51913	140446	1226	541	11	44	0.39

Stock structure

The stock structure (Fig. 1.) analysis indicates that samples obtained from the population slightly deviated from the normal distribution. Males constituted 44.75% (n=691) and females 55.25% (n=853) with an overall sex ratio (Male: Female) of 1.3. No significant difference was observed between the mean CW of male populations (109.26 mm) and female population (110.2 mm) (Independent t-test, $p \leq 0.05$). Minimum and maximum CW were 61.0 mm and 161.0 mm in males and 67.0 and 163.0 mm in females. The mean CW of sex pooled data was found to be 109.8 mm. The annual length frequency distribution revealed that the abundant size group in the crab stock mainly consisted of individuals of 110.0 mm to 115.0 mm CW (mode CW = 112.0 mm).

Carapace width (CW)-weight relationship

The relationship between CW-body weight for the sex pooled data (Fig. 2.), showed that growth was isometric. The relationship between carapace width and body weight for male and female was derived as:

Male: $W = 0.0001 \, CW^{2.94}$ ($r^2=0.93$, n=544)

Female: $W = 0.00007 \, CW^{2.97}$ ($r^2=0.96$, n=508)

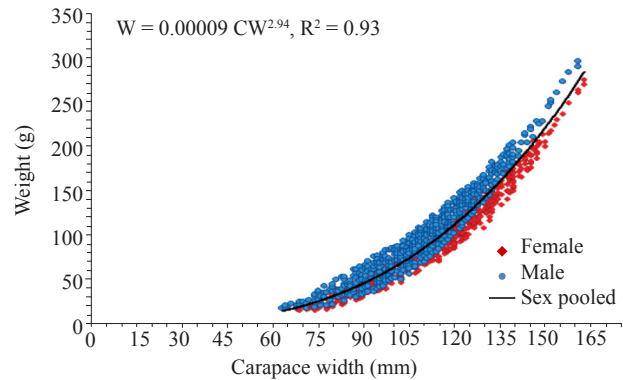where, W is weight in g and CW is carapace width in mm. No significant difference was observed between

Fig. 2. Carapace width and weight relationship of *C. feriata* (sex pooled data) from Veraval waters

the slopes of the regression lines ($p \geq 0.05$) whereas, the intercept of male was found to be significantly higher than the female ($p \leq 0.05$). This suggests that in the present population, the males are heavier than female of similar size. This concurs with the earlier findings where males were found to be heavier than females in *C. feriata* (Dineshbabu, 2011) and other portunid crabs (Laithadevi, 1985, Sukumaran and Neelakantan, 1997; Dineshbabu *et al.*, 2007). This difference may be due to the variation in cheliped size, foraging behaviour and metabolic rate between the sexes (Miyasaka *et al.*, 2007; Thirunavukkarasu and Shanmugam, 2011).
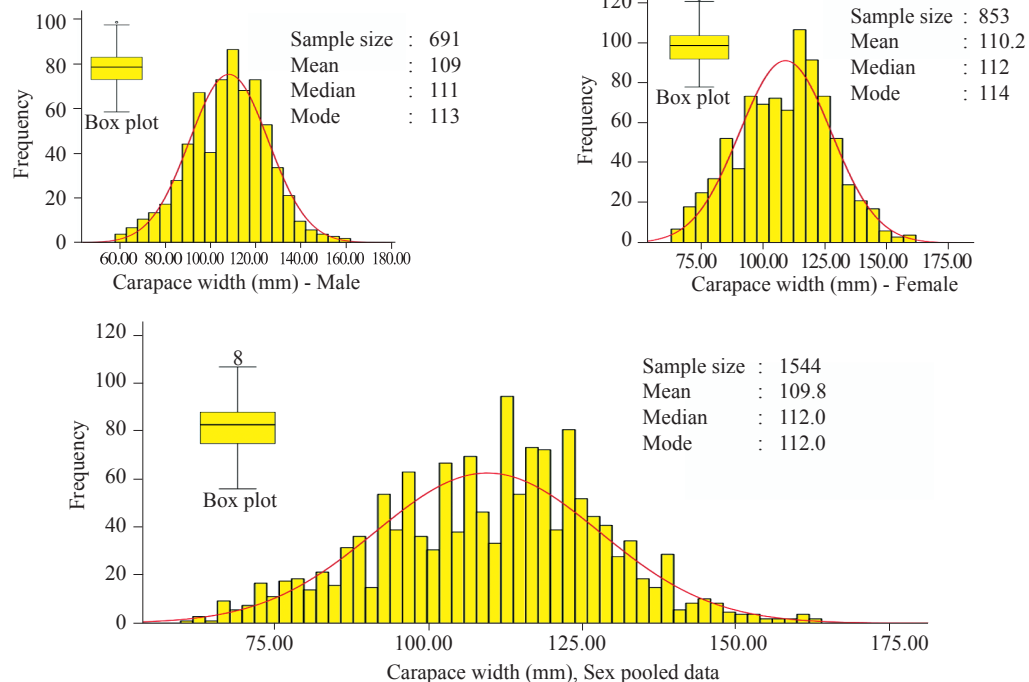

Fig. 1. Population structure of *C. feriata* at Veraval during 2009 and 2011

Growth parameters

The estimated growth parameters derived using male, female and sex pooled data is shown in Table 2. The growth estimated by von Bertalanffy's growth equation showed that the male crab atained 113 mm (CW) in 1st year, 149 mm (CW) in 2nd year and 163 mm (CW) in 3rd year, whereas, the female crab reached 111 mm (CW) in 1st year, 150 mm (CW) in 2nd year and 165 mm (CW) in 3rd year. The restructured length frequency distribution and growth parameters of sex pooled data is shown in the Fig. 3. The L_∞ (175.5 mm for female and 171 mm for male) and K (0.91 yr^{-1} for female and 0.98 yr^{-1}) of *C. feriata* obtained in the present study can be compared with the earlier reported L_∞ (164 mm for female and 173 mm for male) and K (0.89 yr^{-1} for female and 0.84 male) obtained from Karnataka waters (Dineshbabu *et al.*, 2011). The estimation of growth parameters by ELEFAN is greatly influenced by L_{max} (maximum length in sample) and

corresponds to the size (L_{max} which is approximately 95% of L_∞) at which 99% individuals in an unexploited stock dies (Alagaraja, 1989). In the present study, the longevity (t_{max}) of the species was estimated to be 3 year.

Mortality, exploitation and virtual population analysis

The natural mortality rate (M), fishing mortality rate (F) and the total mortality rate (Z) was found to be higher in males compared to female whereas, the current exploitation rate (E_{cur}) was same for both the sexes (Table 2). The M, Z, F and E_{cur} obtained using the sex pooled data is shown in Fig. 4. The estimated natural mortality rate (M) is important to understand rate of stock decay. But 'M' is a difficult parameter to estimate in an exploited resource (FAO, 1993). The 'F' (2.48 yr^{-1}) observed in the present study, was higher than 'M' (1.49 yr^{-1}) as a result of which E_{cur} (0.62) was found to be higher than the optimum exploitation rate of 0.5 (Gulland, 1971).

Table 2. Growth parameters of *C. feriata* from Veraval waters during 2009 and 2011

Sex	von Bertalanffy's growth parameters			Growth performance index	Mortality rates			Exploitation rate
	L_∞	K	t_0	φ	M	Z	F	E_{cur}
Male	171.0	0.98	-0.10	2.46	1.50	4.19	2.69	0.64
Female	175.5	0.91	-0.10	2.45	1.40	3.92	2.52	0.64
Pooled	171.5	0.97	-0.10	2.46	1.49	3.97	2.48	0.62

Elefan I: *Charybdis feriata* (Sex pooled data)
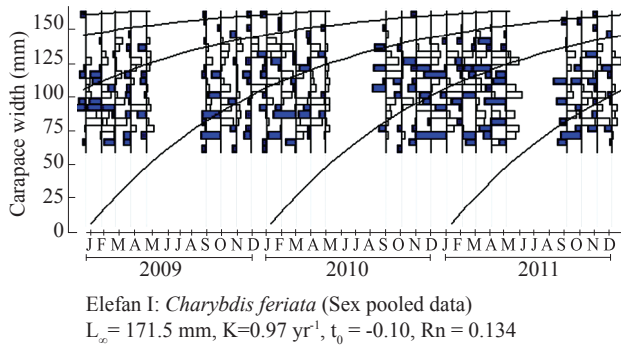L_∞ = 171.5 mm, K=0.97 yr^{-1}, t_0 = -0.10, Rn = 0.134

Fig. 3. Restructured growth curve of *C. feriata* from Veraval waters

hence varies from location to location. However, the growth performance index (φ) (female: 2.45 and male: 2.46) obtained in the present study was found to be in the reasonable range within the family (2<φ<3) (Pauly and Munro, 1984). The growth rate (K) of male in the present study was found to be comparatively 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}) of a species

Virtual population analysis showed that F changes with crab size (CW) which may be attributed to the variation in selectivity of the fishing gear. F was low (< 0.1) for crabs of 65-70 mm CW and it crossed 1.0 when crabs attained CW of 105 mm. However, at LM_{50} (87.3 mm) the F was below 0.5 and exceeded M

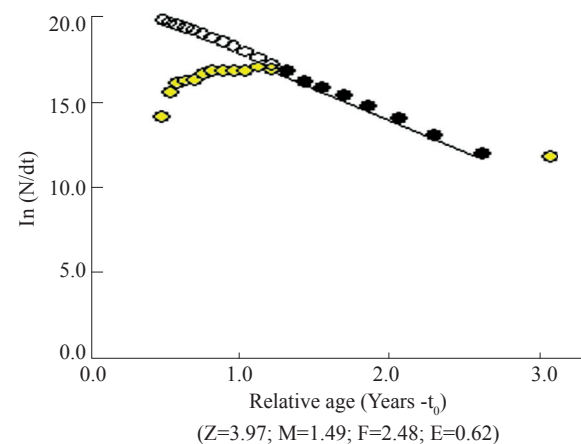(Z=3.97; M=1.49; F=2.48; E=0.62)

Fig. 4. Estimation of Z of *C. feriata* from Length converted catch curve method (sex pooled data)

when the crabs attained CW of 110 mm. Maximum fishing mortality (2.5) was observed at CW of 120-125 mm (Fig. 5).
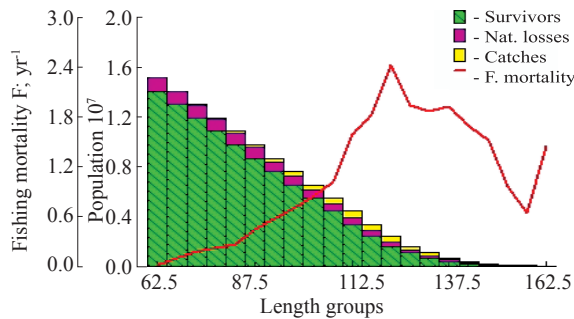

Fig. 5. Length structured VPA for *C. feriata* from Veraval waters

Gear selectivity and maturity

Length at recruitment (Lr) for *C. feriata* was found to be 62.5 mm. Logistic regression of the probability of capture for sequential length classes obtained from length converted catch curve analysis using trawl type selection revealed that 50% of the crabs in stock (L_{50}) became vulnerable to gear when they attained CW of 95.4 mm. The L_{25} and L_{75} were 90.4 mm and 100.3 mm, respectively (Fig. 6). Mature and berried females were recorded throughout the entire fishing period. Maturity study revealed that, 50% of the crabs in stock (Lm_{50}) were mature at CW of 87.3 mm (Fig. 7). In the present study, the L_{50} is found to be higher than Lm_{50} which indicates that crabs enter into peak exploitation phase after attaining sexual maturity which is desirable for the regeneration of
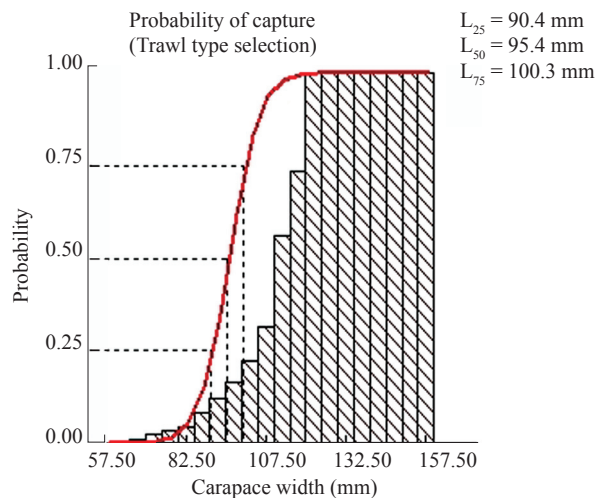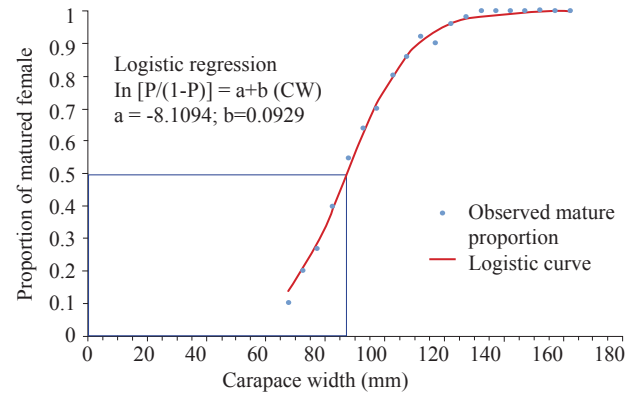

Fig. 7. Size at maturity (LM_{50}) of *C. feriata* from Veraval waters

the stock. The Lm_{50} in the present study is found to be higher than the earlier reported 70 mm from Karnataka waters (Dineshbabu, 2011). Maturity of brachyuran crabs is influenced by environmental factors such as water temperature and salinity that varies from location to location and therefore, shows geographical variations (Hines, 1989; Fisher, 1999). However, the uncertainty factor associated with L_{50} and Lm_{50} should not be ignored as the analysis does not give any weightage for the smaller sized crabs missing in the samples, which are often discarded at sea.

Stock assessment

The relative Y/R and B/R of *C. feriata* were estimated using selection ogive procedure of FiSAT II (Fig. 8). "Selection ogive" was used for the analysis as the "knife edge selection" could lead to substantial bias for the short lived, fast growing tropical species (Pauly and Soriano, 1986; Silvestre, *et al.*, 1991). Moreover, the assumptions
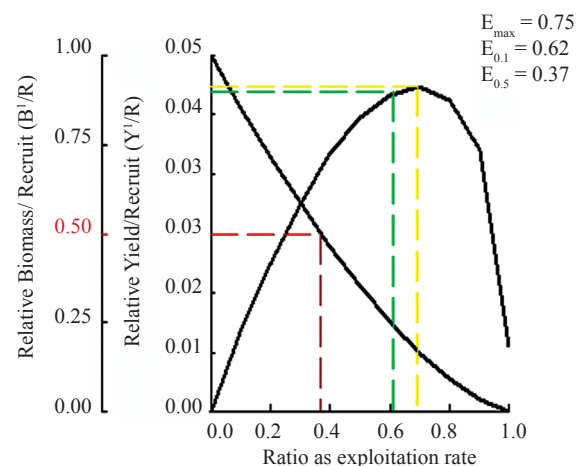

Fig. 6. Length at capture (L_{50}) of *C. feriata* from Veraval waters

Fig. 8. Relative yield per recruit analysis of *C. feriata* from Veraval waters

in the "knife edge selection" are rarely met in the natural condition. L_{50}/L_{∞} as 0.556 and M/K as 1.535 were used as the input parameters for the analysis. The analysis indicated that, the exploitation rate which maximises yield per recruit (E_{max}) was 0.75. In case of r-selected species maximum yield is achieved at higher rate of exploitation compared to the k-selected species which suggests that r-selected species can sustain higher fishing mortalities (Silvestre, *et al.*, 2004; Clarke, 2005). Since, *C. feriata* is a small, fast growing tropical crab species having higher natural mortality, it can be characterised as r-selected species. But there are certain issues in using E_{max} as a management reference point because it tends to be unrealistically high for small tropical species with high natural mortality (Gulland, 1983; Pauly, 1984). Moreover, E_{max} usually corresponds to a very low level of biomass. Therefore, it is often recommended to reduce exploitation to a precautionary safe 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).

Both E_{max} and $E_{0.1}$ are often used as proxies for maximum sustainable yield (MSY) and maximum economic yield (MEY), and set as management reference points (Jakubaviciute, *et al.*, 2011). In the present study, $E_{0.1}$ obtained is equal to E_{cur} which indicates that the fishery is running at economic reference point (MEY). Another reference point used for fisheries management is $E_{0.5}$ which corresponds to exploitation rate at which the B/R reduces by 50% compared to virgin stock *i.e.*, to the level which theoretically maximises surplus production (Pauly, 1984). $E_{0.5}$ is also used as a proxy for the optimum sustainable yield (OSY) (Dadzie *et al.*, 2005). In the present study, the optimum biomass of *C. feriata* can be maintained at $E_{0.5}$ of 0.38 whereas, the E_{cur} (0.62) is high and reducing the B/R considerably. Since, B/R and E can be used as proxies for catch rate (CPUE) and effort (F) respectively, it shows that the catch rate decreases with the increase in effort. But this decrease in CPUE should not be necessarily treated as growth overfishing which occurs only at very high fishing effort (usually above F_{MSY}), where growth cannot balance the death process (Sparre and Venema, 1998). Moreover, as far as recruitment overfishing is concerned, it is necessary to understand the relationship between spawning stock biomass (SSB) and recruitment. Since this relationship in the present crab fishery is unknown and we are assuming a constant recruitment over the period in Y/R analysis, it will be difficult to comment over recruitment over fishing. In such situations, where stock-recruitment relationship cannot be established (Restrepo and Powers, 1999) or the recruitment is independent of stock size (Myers, 2001), reference points such as F_{MAX} (fishing effort that gives maximum yield per recruit) or $F_{0.1}$ (10% gradient in yield per recruit curve) are often recommended.

Spawning stock biomass (SSB) can be used as recruitment fishing reference point which is essential for maintaining the recruitment in the future (Clark, 1991). SSB should be maintained at 20% for stocks having average resilience and at 30% for poorly understood stocks (Mace and Sissenwine, 1993). Therefore, in case of stocks where the relationship between spawning biomass and recruitment cannot be established, it is advisable to use precautionary management reference point such as SSB to prevent recruitment overfishing (Rosenberg and Repestro, 1996). In the present study, Thompson and Bell bio-economic analysis showed that the present fishing level has already achieved the MEY while maintaining the SSB at about 36% of SSB_0 (Fig. 9).

In this scenario if the management targets economic objective, exploitation can be allowed at the present fishing level. Since the stock recruitment relationship is not clearly defined, as a precautionary approach, SSB at about 30% of SSB_0 should be considered as a biologically safe management reference point. Considering this, fishing level (F-factor) can be increased by 1.3 times the present level without jeopardising the biological management objective, but this will marginally decrease MEY. The analysis also showed that yield can be increased from 464.4 t (current equilibrium yield) to 513.5 t (MSY) by increasing fishing level (F-factor) by 2.4 times the present value. However, the estimated F_{MSY} would deplete the SSB to 20% of virgin spawning stock biomass (SSB_0) and economic yield by 14% of MEY. Poorly understood stock gives rise to uncertainty in the estimation of stock parameters which affects the accuracy of management reference point. For example, maximum sustainable yield (MSY), though has been proposed as a universal objective for the fisheries management, it is not widely adopted as it does not give an accurate estimation of status for many stocks, especially where stock-recruitment relationship is poorly established (Edwards *et al*., 2012). Therefore, in the event of uncertainty, precautionary approaches should be taken in to account for management decision making (FAO, 1996). Since *C. feriata* is a non-targeted resource in this region, consideration should also be given to the
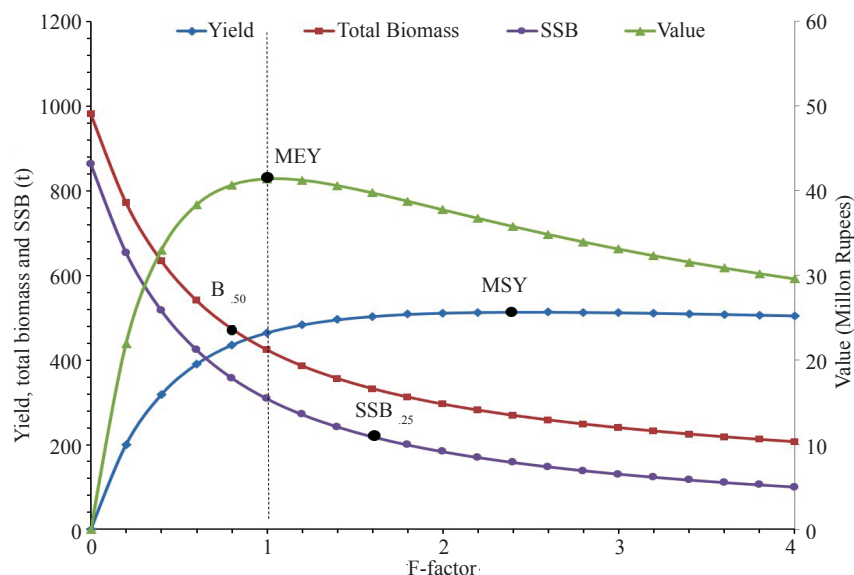
Fig. 9. Length based Thompson and Bell analysis of *C. feriata* from Veraval waters

demand and exploitation status of other targeted fishery resources while arriving at suitable management reference points.

Acknowledgements

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