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Growth, mortality and exploitation of buccaneer anchovy (*Encrasicholina punctifer* Fowler, 1938) from the north Persian Gulf and Oman Sea

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Abstract

The population parameters of *Encrasicholina punctifer* (buccaneer anchovy) from commercial fisheries in the Persian Gulf and Oman Sea coastal waters were studied from October 2014 to September 2015. A total of 13951 length-frequency data were collected monthly by pair-boat purse seine and beach seine methods. The asymptotic length ($L\infty$) and Von Bertalanffy growth function (K) were 11.5 cm and K=1.4 per year, respectively. The value of t_o was calculated as -0.14 year. Longevity was estimated as 2 years. The total length ranged from 2.9 to 10.1 cm, with an average of 6.5 cm. The probability of capture was calculated in total length as L_{25}=6.05 cm, L_{50}=6.48 cm and L_{75}=6.93 cm. Four cohorts were distinguished annually with mean lengths of 4.56, 5.77, 7.21 and 8.50 cm. The length-weight relationship was determined as $W= 0.0051\ L^{3.1114}$. Total, natural and fishing mortality parameters were estimated as 6.15, 2.84 and 3.32 yr^{-1} respectively. The current rate of exploitation (E) was 0.54, and the values of exploitation ratio was found reasonable for current fishing effort. From the yield-per-recruit analysis, E_{max}, was estimated as 0.91. The results indicated that the buccaneer anchovy stock was not overexploited. Since $E<E_{max}$, it confirmed the good potential of anchovy stock in the area.

Keywords: *Encrasicholina punctifer*, Growth, Mortality, Persian Gulf, Oman Sea

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Introduction

Anchovies are also ecologically important, because their large biomass is a link in coastal food-webs, transferring the energy in plankton and small organisms to larger fishes, sea birds and marine mammals (Ganias, 2014). Buccaneer anchovy (*Encrasicholina punctifer)* belonging to the family Engraulidae, is an important small pelagic fish occurring in commercial quantities in the north of the Persian Gulf and Oman Sea coastal waters. In recent years, anchovy fisheries increased due to the development of pair-boat purse seine in the Iranian coastal waters (Alizade and Oliaei, 2015). The estimated potential yield for anchovies in the Persian Gulf and Oman Sea was calculated around 173000 tons (FAO, 1981). Buccaneer anchovy is the dominant species of anchovies in the study area (FAO, 1981; Owfi, 1991; Van Zailinge *et al*., 1993). Fishing season of buccaneer anchovy in the Persian Gulf and Oman Sea starts from early autumn to late spring, the peak of fishing has been reported in winter (Alizade and Oliaei, 2015). Over 99% of anchovies landing in Iranian adjacent waters comes from the three major fishing grounds including Bandar Lengeh, Qeshm Island and Bandar Jask areas (Qorbanzadeh and Nazari, 2012). Landing of 37000 tons anchovies was reported by Alizade and Oliaei (2015) from the study area in 2014. The buccaneer anchovy is broadly distributed throughout the Indo-Pacific region and has been reported from several locations, including the east coast of Africa, India, Persian Gulf, southeast Asia, Japan, the Philippines, the central tropical Pacific and Hawaii (Strasburg, 1960, Whitehead *et al*., 1988). Buccaneer anchovy is a schooling epipelagic species found both in inshore and oceanic waters, sometimes entering large atoll lagoons or deep, clear bays (Maack and George, 1999). It is a small pelagic schooling fish, with a total length of 10 cm (Paula de Silva, 1992) and a short life span of around one year (Rohdenburg, 1995). Ranks among the most important food (bait) for tuna and other large pelagic fishes (Myers, 1999; Itano, 2000; Mundy, 2005). In particular, the *E. punctifer* appears to be a major forage source for yellowfin tuna, longtail tuna, Kawakawa and large hairtail, occupying a significant ecological role in the region (Darvishi *et al*., 1993; Kamali *et al*., 2003; Daghooghi *et al*., 2010). The species is well known from coastal locations (Sreekumari, 1977; Young *et al*., 1995) but appears to be primarily an offshore species and the only member of the anchovy group capable of completing the life cycle in the oceanic environment (Gorbunova, 1973; Orlov, 1995). This species usually occurs in shallow waters from 5 to 35m depth, with highest density around the islands and creeks mouth (Myers, 1999; Fricke *et al*., 2011). Most of studies on population structure of *E. punctifer* resources, have been carried out in the Philippines (Pauly, 1978; Ingles and Pauly, 1984, Lavapie-Gonzales *et al*., 1997) and Mozambique (Paula de Silva, 1992). Reproduction and feeding of *E. punctifer* were studied by Maack and George (1999) and Chern and Tzeng (1993). Several studies have been conducted in order to study population dynamics and biology of *E. punctifer* in Persian Gulf and Oman Sea (Salarpouri *et al*., 2007 ; Salarpouri *et al*., 2008; Ataei Daryaei *et al*., 2013). Because very little is known about the population parameters and exploitation levels of *E. punctifer* in the Persian Gulf and Oman Sea, this study was undertaken to fill some of these gaps.

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Materials and methods

The study area

The study area was the coastal waters of Bandar Lengeh, Qeshm Island and Bandar Jask fishing areas, situated between 52° 30' E and 58° 30' E longitude (Fig. 1), located in the north Persian Gulf and Oman Sea, has a high level of biodiversity, supporting a wide variety of fish species.

Data sampling

Time series of *E. punctifer* length–frequency from the commercial pair–boat purse seine and beach seine catches were collected monthly based on simple random sampling in the Persian Gulf and Oman Sea fishing grounds from October 2014 to September 2015. A total of 13951 specimens were collected for further length measurement.

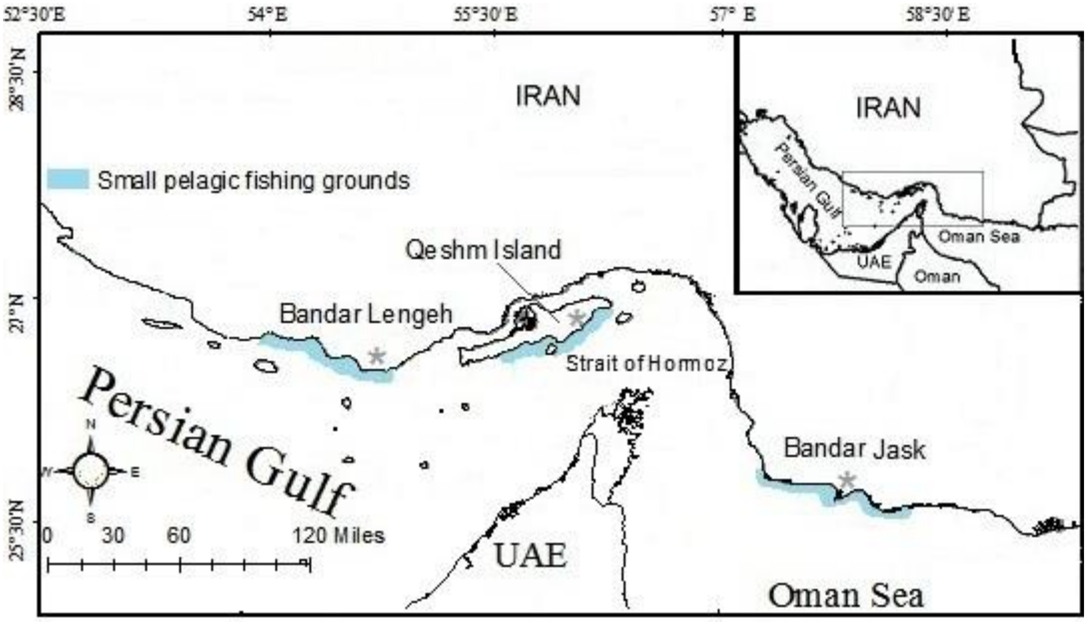

Figure 1: Map of the study area in the Persian Gulf and Oman Sea

Data analysis

The method of Sparre and Venema (1998) was used. During each sampling day, random sub-samples of fish were obtained from well-mixed catches. The total length and weight were recorded to the nearest mm and gram, respectively. Generally, at least 350 fish were measured in each sampling area and month, except where catches were quite poor. The chosen sample size provided a reasonable database for analysis (Gulland and Rosenberg, 1992). The length-weight relationship was determined from Sparre and Venema (1998) using the least squares method:

$W=aL^b$

The length data were pooled and grouped into 0.5 cm size class in order to have about 16 length classes, as suggested by (Gayanilo *et al*., 2005). Growth parameters were determined using FiSAT (FAO–ICLARM Stock Assessment Tools) software (Gayanilo and Pauly, 1997). The Von Bertalanffy growth equation was used to describe growth in length (Sparre and Venema, 1998):

$L_t= L\infty\ [1-\exp(-k\ (t- t_0))]$

Where L_t is the total length (cm) of a fish at age t, $L\infty$ is the asymptotic length (cm), K is growth coefficient ($year^{-1}$), and t_0 is age (year) when L=zero (Sparre and Venema, 1998). T_0 was calculated from Pauly (1983) empirical function:

$Log_{10}(-t_0)=-0.3922-0.2752Log_{10}(L\infty)-1.038Log_{10}(K)$

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The starting point may be fixed or variable. The variable starting point allows for several possible choices of the starting points and only that with the best fit is retained (Gayanilo and Pauly, 1997). The seeded value of $L\infty$ used was Lmax, and the largest length was observed during the course of this study, which was 10.1 cm total length. For comparison of the Von Bertalanffy growth of *E. punctifer* studied with other anchovy species, the following formula was used for comparison of the Von Bertalanffy growth parameters (Pauly and Munro, 1984).

$\acute{Ø} = \text{Log}_{10} K + 2\ \text{Log}_{10} L\infty$

The length-converted catch curve accounting for growth was employed to estimate the total mortality, as incorporated in FiSAT (Gayanilo and Pauly, 1997). The instantaneous rate of total mortality coefficient Z was therefore estimated using the following formula:

$$N_{i+1} = N_i \times e^{-Z(t_{i+1}-t_i)}$$

Where N_i is the (initial) number of fish at time t_i, N_{i+1} the number of fish remaining at time t_{i+1} and Z the instantaneous rate of total mortality (Gayanilo and Pauly, 1997). An advantage of such decay rates is that they can be added or subtracted. Thus, there is a second equation:

$Z = M + F$

where M is the instantaneous rate of natural mortality and F the instantaneous rate of fishing mortality; when $F = 0$, $Z = M$, which means that natural mortality has the same value as total mortality when there is no fishing, i.e. an unexploited stock. Natural mortality, fishing mortality and exploitation rates were all calculated as given by FiSAT (Pauly, 1983; Gayanilo and Pauly, 1997). For the calculation of the natural mortality, the mean environmental temperature, in this case 26.5C° (Ebrahimi *et al*., 2005; Ebrahimi *et al*., 2006; Ebrahimi *et al*., 2012) was incorporated into the Pauly (1980) formula as found in FiSAT. Pauly's empirical formula was used to determine natural mortality:

$\text{Log}_{10}(M)=-0.0066-0.2791\ \text{Log}_{10}(L\infty) +0.6543\ \text{Log}_{10}(K)+0.4634\ \text{Log}_{10}(T)$

The exploitation rate (E) was estimated using the following formula:

$E = F/Z$

The probability of capture for anchovy fishery was estimated from the left ascending arm of length-converted catch curve. The right descending part of the catch curve was extrapolated backward such that fish that ought to have been caught, had it not been for the effect of incomplete selection or recruitment, were added to those in the curve, with the ratio of expected numbers to those that are actually caught being used to estimate probabilities of capture. By plotting the cumulative probability of capture against mid-length, a resultant curve was obtained. From this curve, the length at first capture Lc was taken as corresponding to the cumulative probability at 50%. The entire length–frequency data were used to reconstruct the seasonal recruitment pattern of the fish by projecting backward along a trajectory defined by the computed VBG function, all the restructured length–frequency data on to a 1-year time scale (Pauly, 1987). The potential longevity of *E. punctifer* was calculated using the formula given by Pauly and Munro (1984):

$T\text{max} = 3/K$

The relative yield-per-recruit model of Beverton and Holt (1956) was modified by Pauly and Soriano (1986) and incorporated in the FiSAT Programme. The knife-edge selection and selection Ogive procedures were used to estimate relative yield/biomass per recruit. The computed exploitation rate was compared with the expected values of Emax (the value of

[DOR: 20.1001.1.15622916.2018.17.2.5.5]

exploitation rate giving maximum relative yield-per-recruit), $E_{0.1}$ (the value of E at which marginal increase in Y/R is 10% of its value at $E = 0$) and $E_{0.5}$ (the value of E at 50% of the unexploited relative biomass-per-recruit)(Gayanilo and Pauly, 1997; Sparre and Venema, 1998). The yield isopleths diagram was used to assess the impact on yield created by changes of exploitation rate E and the ratio of length at first capture to asymptotic length (Lc /$L\infty$) in relation to changes in mesh size.

Results

Morphometrics

The total length ranged from 2.9 to 10.1 cm, with average 6.5±1.18 cm. The total weight ranged from 0.56 to 6.36 g, with average 2.17±0.95 g.

Length weight relationship

The length–frequency class given in Fig. 2, the most frequent of length class was calculated as 6.5-7.0 cm. The relationship between length (cm) and weight (g) was estimated for 2172 specimens (both sexes) as $W= 0.00515L^{3.1114}$(R^2=0.91) (Fig. 3).

Growth parameters

The estimation of growth parameters of *E. punctifer* is given from monthly length frequency. The asymptotic length, $L\infty$ was 11.5 cm; growth rate, K was 1.4 per year, t_0 was -0.14 yr; without respect to seasonal oscillation. The above estimates of growth parameters were obtained from length frequency analysis using ELEFAN I program incorporated in FiSAT II and growth curve so obtained is shown in figure 4. The growth performance index, Ǿ was 2.26. The potential longevity of *E. punctifer* was estimated at 1.99 years or approximately 24 months. This represents the maximum life span of *E. punctifer* in its natural environment. Four cohorts were distinguished annually on Bhattacharya's method with mean lengths of 4.65, 5.77, 7.21 and 8.50 cm. The recruitment pattern is given in Fig. 5, indicating double recruitment peaks per year. The major recruitment peak occurred at 16.03% in September.

Mortality and exploitation rate

From the length-converted catch curve procedure (Fig. 6) total mortality Z, was estimated at 6.15 per year, while natural mortality (M) of 2.84 per year was estimated from Pauly (1980) empirical formula. The fishing mortality (F) of 3.32 per year was obtained. The exploitation rate (E) was estimated as 0.54 per year. The probability of capture was calculated in total length as L_{25}=6.05 cm, L_{50}=6.48 cm, L_{75}=6.93 cm (Fig. 7). Relative yield-per-recruit and relative biomass-per-recruit as computed using the Knife-Edge selection and Selection Ogive procedures. Yield per Recruit isopleths diagram with M/K=2.02 for *E. punctifer* given in Fig. 8. The yield contours predict the response of relative yield-per-recruit of the fish to changes in Lc (length at first capture) and E (exploitation rate); Lc/$L\infty$=0.56. Lc/$L\infty$ values represent varying scenarios equivalent to changes in mesh size. E corresponds to changing levels of F/Z. The optimum exploitation rates were estimated as follows: E_{max}=0.91; $E_{0.1}$=0.75; $E_{0.5}$=0.38. The dotted line is the computed value of the critical ratio and the exploitation rate is 0.91 (Fig. 9).

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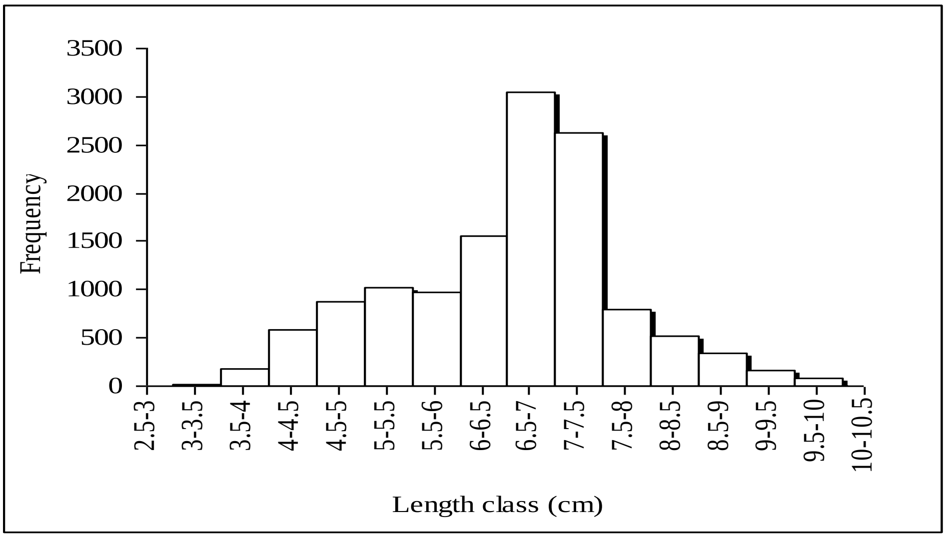

Figure 2: Length frequency distribution for *Encrasicholina punctifer* from the north Persian Gulf and Oman Sea.

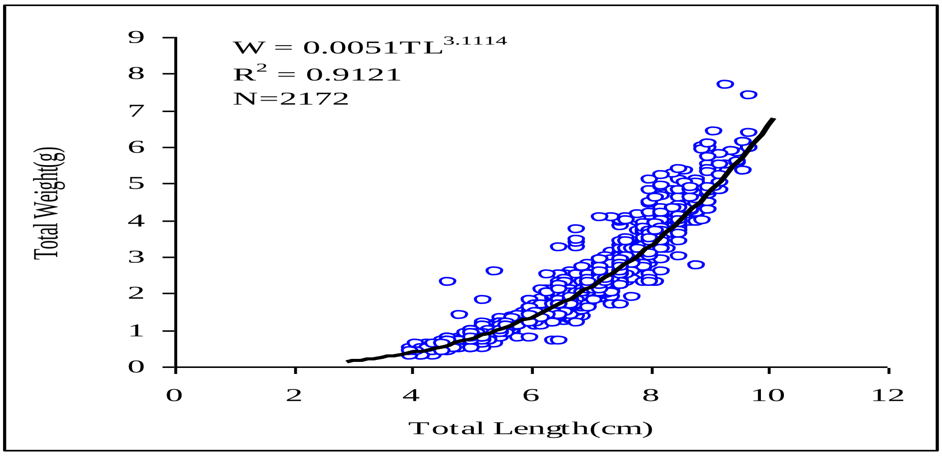

Figure 3: Length-weight relationship curve for *Encrasicholina punctifer*.

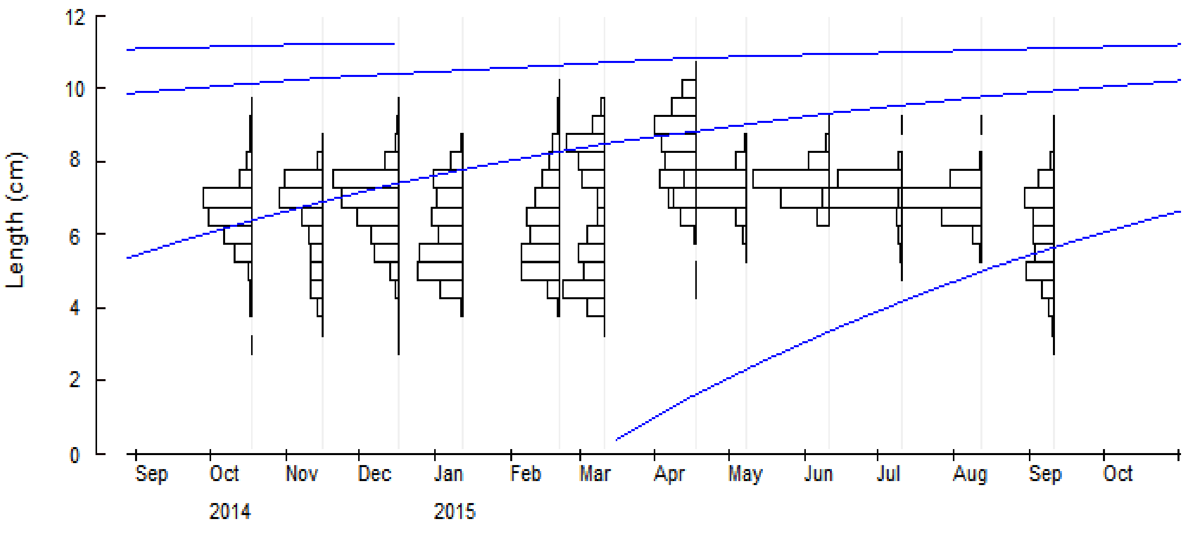

Figure 4: Restructured length- frequency histogram for *Encrasicholina punctifer* with super imposed growth curve (L_∞=11.5 cm, K=1.4 per year, t_0=-0.14, Ǿ=2.26).

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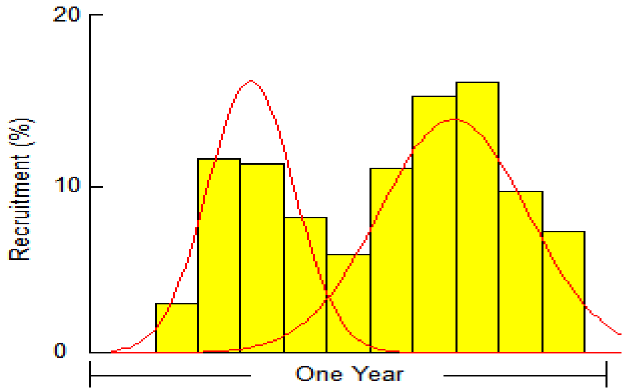

Figure 5: Recruitment pattern of *Encrasicholina punctifer,* indicating double peaks per year.

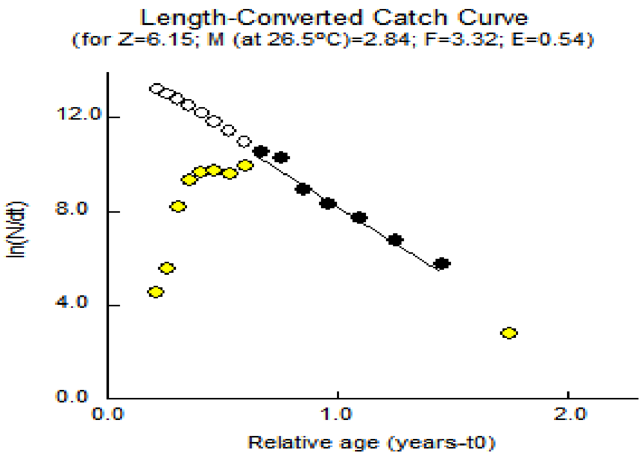

Figure 6: Length-converted catch curve for *Encrasicholina punctifer*. Regression statistics: *y*-intercept, *a* = 15.16; slope, *b* = -6.15; *r* = 0.98; *n* = 7; *Z* =6.15 per year.

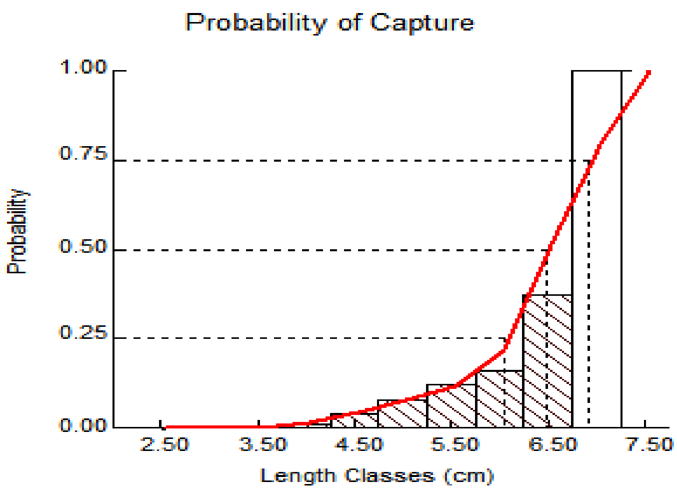

Figure 7: Probability of capture of each length class of *Encrasicholina punctifer* (L_{25}=6.05 cm, L_{50}=6.48 cm, L_{75}=6.93 cm).

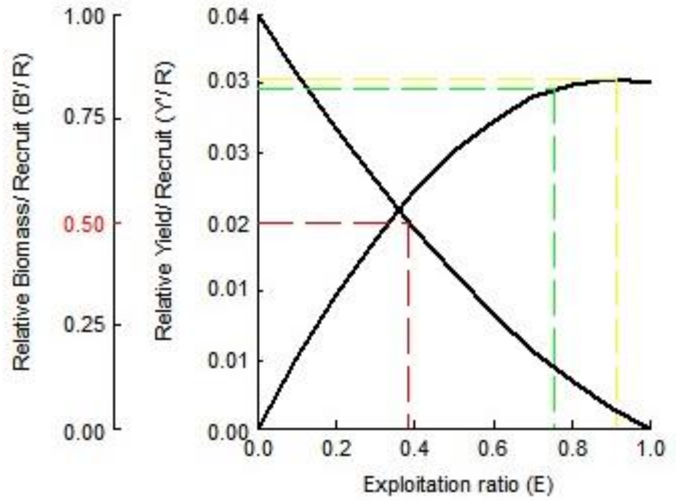

Figure 8: Yield per Recruit isopleths diagram with *M/K* = 2.02 for *Encrasicholina punctifer*. The yield contours predict the response of relative yield-per-recruit of fish to changes in *L*c (length at first capture) and *E* (exploitation rate).

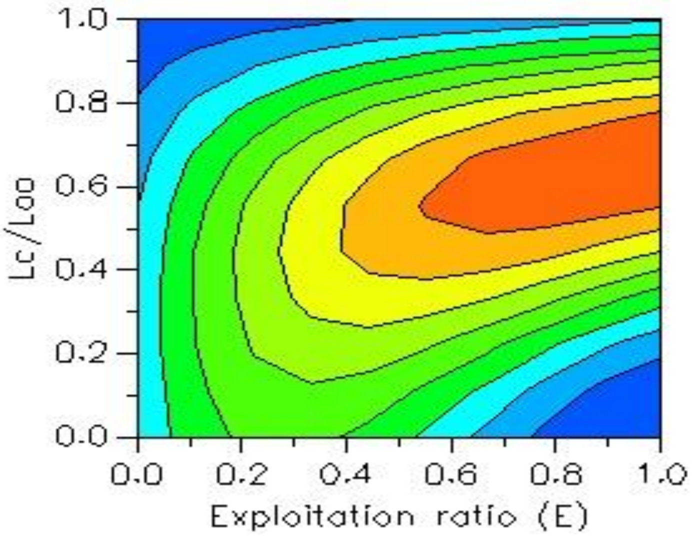

Figure 9: Relative yield-per-recruit and relative biomass-per-recruit as computed using ogive selection (E_{max} = 0.91, $E_{0.1}$ = 0.75, $E_{0.5}$ = 0.38).

Discussion

In this study, the total length of *E. punctifer* ranged from 2.9 to 10.1 cm, with an average of 6.5±1.18 cm. Whitehead *et al*. (1988) reported the maximum length for *E. punctifer* at 13 cm. The range of total length for *E. punctifer* from Mozambique were reported between 2.75 to 10.25 cm (Paula de Silva, 1992). The total length of *E. punctifer* ranged between 5.0 and 10.5 cm with major mode at 8.5 cm in the Indian coastal waters (Agenbag *et al*., 2003; Rohit and Gupta, 2008). A closer look at the length–frequency data in Fig. 2 will readily show the normally distributed *E. punctifer* stock with more middle aged fishes in the Persian Gulf and Oman Sea coastal waters, confirming that the gear mesh size are not suitable for anchovy fishing, and maybe the stock is going to be subject to fishing pressure (Gayanilo and Pauly, 1997). The *a* and *b* coefficients of

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the length-weight relationships were estimated as 0.0051 and 3.11 respectively. The value of *b*=2.87 for *E. punctifer*, *b*= 3.12 for *E. devisi* were reported from India (Rohit and Gupta, 2008), and *b*=3.12 for *E. punctifer* from Indonesia (Maack and George, 1999). In general, *b* values of fishes are closer to 3, despite the many variations of fish forms (King, 2007). Length- weight relationships are required in population dynamics and fisheries stock assessment (Gulland and Rosenberg, 1992). Several factors affect the accuracy of the length-weight relationships, e.g., condition of fishes caught in different seasons, sex, length ranges, sample size and fishing methods (Haimovici and Canziani, 2000).

In this study, the growth rate *K*=1.4 year^{-1} and the asymptotic length $L\infty$=11.5 cm. A comparison of growth performance of *E. punctifer* from different sources is given in Table 1. Generally, the growth performance index (Ǿ) is a species-specific parameter, i.e. its values are usually similar within related taxa and have narrow normal distributions. Gross dissimilarity of Ǿ for a number of stocks of the same species or related species is an indication of the unreliability in the accuracy of estimated growth parameters (Moreau *et al*., 1986). It must be realized however, that Ǿ can be used only to compare the growth performance of fish with similar shapes (Gayanilo *et al*., 2005). Preliminary analyses Moreau *et al*. (1986) suggest that the C.V. of Ǿ for several stocks of the same species should not exceed 5 percent, which may provide some guidelines as to which values of Ǿ are credible and which are not (Gayanilo and Pauly, 1997). The coefficient of variation of 4.04% together with other measures of dispersion (range = 0.24, SD = 0.093 and mean = 2.30) for Ǿ values in Table 1 is low. The Ǿ=2.26 of buccaneer anchovy in this study is; however, next to the other studies. Such differences can result partially from the different techniques used but more likely reflect slight environmental differences such as food availability, temperature, etc. (Ragonese and Bianchini, 1998). The similarity in the relative growth performance of this tropical anchovy and those from other regions suggests that phylogeny may influence growth independent of local environmental conditions. It also suggests that their position in the food web as lower-order secondary consumers places a constraint on overall growth performance in any environment (Milton *et al*., 1993).

Four cohorts were distinguished annually with mean lengths of 4.56, 5.77, 7.21 and 8.50 cm. The double recruitment peaks per year obtained here (Fig. 5) conform to the assertion of Pauly (1982) that the double recruitment pulses per year are nearly a general feature of tropical fish species. Sardine and anchovy, present peculiarities in their population dynamics and interesting phenomena are related to their recruitment (Bakun, 2010; Petitgas *et al*., 2012). Tropical species are known to have recruitment all through the year (Sparre and Venema, 1998). Recruitment of small pelagic fishes, especially anchovies, fluctuates widely in response to both fishing and environmental effects. Yet, their life history style is extremely flexible and enables populations to persist, even at very low levels (Beverton, 1990).

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Table 1: Comparison of growth performance of the *Encrasicholina punctifer* (Mean=2.30, range= 0.24, CV=4.04, S.D. =0.093).

Ǿ	L∞	K	Area	Source
2.22	11.6	1.23	Philippine	(Pauly, 1978)
2.32	10.6	1.85	Philippine	(Ingles and Pauly, 1984)
2.46	12	2	Mozambique	(Paula de Silva, 1992)
2.27	12.4	1.2	Philippine	(Lavapie-Gonzales *et al*., 1997)
2.26	11.5	1.4	Persian Gulf and Oman Sea (Iran)	This study

The instantaneous rates of total mortality Z= 6.15 year^{-1}, fishing mortality F=3.32 year^{-1}, natural mortality M=2.84 year^{-1} and exploitation rate E=0.54 were estimated in this study. Rohit and Gupta (2008) were estimated the rates of Z= 8.97 yr^{-1}, F=5.79 yr^{-1}, M=3.18 yr^{-1} and E=0.65 for *E. punctifer*, the rates of Z= 8.19 yr^{-1}, F=5.08 yr^{-1}, M=3.11 yr^{-1} and E=0.62 for *E. devisi*, from Indian coastal waters. The rate of mortalities and the exploitation rate in this study were lower than *E. punctifer* and *E. devisi* reported by Rohit and Gupta (2008). The value of exploitation rate (*E*) of 0.54 estimated here confirms that the stock of *E. punctifer* of the Persian Gulf and Oman Sea coastal waters is not experiencing fishing pressure yet. There are obvious factors responsible for the observed optimum fishing. The mortality and exploitation rates showed that the *E. punctifer* population is in suitable fishery conditions. This species studied here comprises predominant coastal small pelagic fishes in this area and the general conclusion to be drawn from these results is that the level of exploitation is near to optimum level of *E*=0.5 (Pauly, 1982). It seems that for short-lived species like anchovy with high reproduction potential, maybe *E* more than 0.5 is reasonable.

With a maximum age of 24 months, *E. punctifer* is a relatively short-lived species and it is confirmed by the high natural mortality recorded in this study. In addition, this result confirms the super imposed growth curve (Fig. 4) from restructured length- frequency. *E. punctifer* lifespan is around a year (Rohdenburg, 1995). Intuitively, we would consider longevity as something more closely related to mortality than *K*, *L*∞ or ambient temperature. As longevity is usually as difficult to observe as the natural mortality the relationship between mortalities and life span does not make it any easier as to estimate *M*, but it presents the concepts in way, which may be easier to grasp (Sparre and Venema, 1998). The short-lived tropical species grow much more rapidly than their temperate relatives, which suggests that they may have better growth performance and therefore be more desirable for culturing (Milton *et al*., 1993). Beverton and Holt (1956) found that values of the ratio *M*/*K* mostly lie in the range of 1.5–2.5 (Sparre and Venema, 1998). In this study, *M/K* for *E. punctifer* was 2.02. The relative yield-per-recruit(*Y/R*) model of Beverton and Holt (1956) estimates *Y/R* values based on few inputs, i.e., mean length at first capture/asymptotic length (*Lc/L*∞), ratio of natural mortality on growth (*M/K*) and exploitation rate (*E=F/Z*) (Pauly and Soriano, 1986). The relative yield per recruit was maximum when the exploitation rate (*F/Z*) was 1. This indicates that F should be very high compressed to *M* so that the ratio *F/Z* tends to be 1.

All these add credence to the validity of the results in this study. The computed current exploitation rate *E* of 0.54 is far from the predicted *E* max of 0.91. The exploitation observation indicated that the *E. punctifer* was in optimum exploitation in the Persian Gulf and Oman Sea region because of fishing activities, gear

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expansion, food availability and spawning success. This further strengthens the argument that the *E. punctifer* stock is not under fishing pressure. Based on the critical size ratio of ($Lc/L\infty$) (which is a proxy of mesh size) and the current exploitation rate *E* which is a proxy of effort, Pauly and Soriano (1986) have shown that relative yield isopleths could be grouped into four categories (quadrants) each with its distinct properties. When compared with the yield isopleths diagram in this study, the $Lc/L\infty$ of 0.56 and exploitation rate of 0.54 falls within quadrant *B* of (Pauly and Soriano, 1986). The implication is that the small fish were caught at lower effort levels.

In conclusion, the analyses of mortality rates, exploitation rates, yield-per-recruit and biomass-per-recruit carried out here all indicate that the purse seine fishery of *E. punctifer* of the Persian Gulf and Oman Sea coastal waters have not yet noticeably put fishing pressure on anchovy stock. Analysis indicates the anchovy fishery is in the growth phase, and it confirmed the reliable potential of anchovy stock in the area. Anchovy stock needs monitoring of the effort level and exploitation rate (*E*), there is no need for interventions. Furthermore, the fishery requires to stabilize its effort to achieve stable exploitation rates in anchovy fisheries.

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