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Population dynamics of the pharaoh cuttlefish *Sepia pharaonis* (Mollusca: Cephalopoda) in the Arabian Sea coast of Oman

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ABSTRACT

The stock of pharaoh cuttlefish *Sepia pharaonis* was assessed based on 4616 specimens (1895 males, 2051 females and 670 unsexed), collected during the demersal fishery survey in the Arabian Sea coast of Oman between September 2007 and August 2008 and from November 2011 to June 2012. Age and growth were studied based on length frequency data using Bhattacharya's method. There was no significant difference in growth between sexes and the longevity was estimated to be five years for mantle length (ML) range 1.7 – 44 cm. The estimated von Bertalanffy growth parameters were L_∞ = 46.21 cm ML, K = 0.52 y^{-1} and t_0 = 0.1 y. The instantaneous rates of total (Z), natural (M) and fishing (F) mortalities were 2.57, 0.997 and 1.57 y^{-1} respectively with exploitation rate (E) of 0.61 and exploitation ratio (U) of 0.66. The estimated ML at first capture (L_c) was 12 cm, while the ML at first sexual maturity (L_m) was 19.60 cm. The yield per recruit model revealed that *S. pharaonis* stock in the Arabian Sea is heavily exploited, but has a scope to increase the yield by increasing the length at first capture to be not less than 20 cm ML. Also, there is an urgent need to protect juveniles and under-sized part of the stock.

Keywords: Age and growth, Arabian Sea, Cephalopods, Mortality and exploitation rates, Oman, Yield per recruit

Introduction

Cephalopods are short lived, carnivorous animals that have rapid growth rates. They differ greatly from other molluscs in that they are more active, fast-moving, intelligent carnivores, with highly advanced visual and nervous systems (Boyle and Rodhouse, 2005). Their high protein and low fat content make them an important and healthy element in the human diet and their utilisation for human consumption is extensive and diverse.

Cephalopod fishery comprising cuttlefish, squid and octopus, in the Oman coastal waters is economically very important, due to the high commercial value in national and international markets. In the past, the cuttlefish was caught as bycatch and didn't have any commercial value. In 90's, increasing attention was paid to this valuable fishery and of late it has become a target species for both artisanal and industrial fisheries in Oman. Cuttlefish constitutes about 16% of the demersals' total catch (Annual fishery statistics book, 2011) earning about 11 million Omani Rial (OR ≈ 2.6$). The major species of cuttlefish in the Omani waters are *Sepia pharaonis* and *Sepia prashadi*. *Sepia pharaonis* (Ehrenberg, 1831) is distributed in Indo-Pacific: Red Sea, Arabian Sea to South China Sea, East China Sea and northern and north-western Australia. It is a neritic, demersal species occurring from the coastline to about 110 m depth, but more abundant in the upper 40 m, particularly during the reproductive season, when it migrates shoreward and aggregates in shallow waters (Fishbase, 2011).

Although cuttlefishes in the Omani coastal waters constitute one of the most economically important groups, only limited studies have been carried out on these species. Meriem *et al.* (2001) conducted stock assessment studies on the pharaoh cuttlefish collected during 1999 from Oman Sea, while Al-Marzouqi *et al.* (2009) studied biology and stock status of the same species collected during 2001-2002 from the Arabian Sea. Mehanna and Al-Mamry (2013) estimated the population parameters for *S. prashadi* in the Arabian Sea. On the other hand, there are studies on the pharaoh cuttlefish in different localities (Sanders, 1979, 1981; Silas *et al.,* 1985; Nair *et al.,* 1993; Abdul Wahab, 2003; Abdussamad *et al.,* 2004; Mehanna *et al.,* 2009). The present study wais undertaken to update and to estimate the basic parameters of *S. pharaonis* stock in the Omani coastal waters aimed at improving its production in a sustainable manner.

Materials and methods

Samples of *S. pharaonis* were collected during the trawl surveys of the Arabian Sea which covered the area between Ras Al-Hadd in the north (23° 39' 10" N and 58° 34' 03" E) and the Omani Yemeni border in the south (16º 37' 26′′ N and 53º 17› 53′′ E) between depths of 20 to 250 m (Fig. 1). Five seasonal surveys with an average duration of 47 days were undertaken onboard RV Al Mustaqila I (46 m length overall, 12.5 m beam, 3602 horsepower, 1745 t displacement) between September 2007

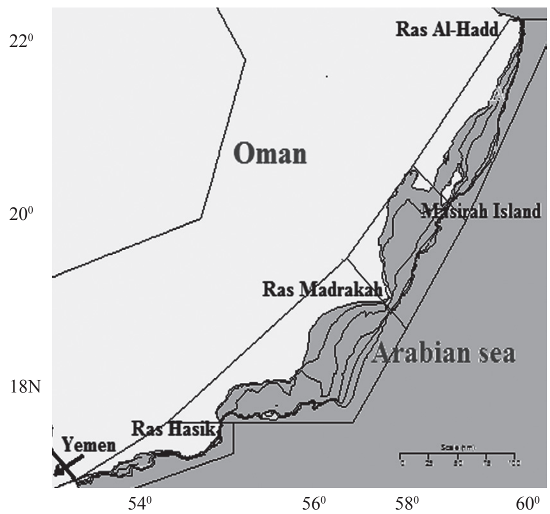

Fig. 1. Oman coast of the Arabian Sea showing the study area

and August 2008. The trawl net used was of 35 m long headline and 38 m long ground line. The cod-end was adapted for the survey with a nominal inside mesh measurement of 40 mm and included an extension section to match with the back end of the trawl and to ensure correct filtration.

A total of 4616 specimen (1895 males, 2051 females and 670 unsexed) were analysed and all specimens were separated by sex after measuring their mantle length (ML) to the nearest mm and their total body weight (BW) to the nearest 0.1 g. The collected samples were grouped into 2 cm ML classes for modal progression analysis (MPA).

The length frequency data was treated by computer based analysis (FiSAT software) for the estimation of population parameters. The following methods were applied in this study: The Bhattacharya method (1967) to distinguish different components from the length frequency data. The length-weight relationship was estimated using the power equation $W = a\,ML^b$ where "W" is the total weight and "ML" is the mantle length. Gulland and Holt (1959) plot to estimate the growth parameters of the von Bertalanffy growth model (L_∞, K and to). Powell (1979) - Wetherall (1986) was used to estimate the L_∞ and Z/K, ELEFAN I method (Pauly, 1987) to estimate the L_∞ and K, Pauly (1983) methods to estimate the total mortality coefficient (Z) and Pauly's (1980) formula to estimate the natural mortality coefficient (M). The fishing mortality coefficient (F) was computed from the equation F = Z – M, while the exploitation rate (E) was computed from the ratio F/Z and the exploitation ratio was estimated as $F/(Z*(1-e^{-Z})$ as given by Beverton and Holt (1957) and Ricker (1975).

The mid length of the smallest length group in the catch was taken as length at recruitment (Lr), while the length corresponding to the first value in the descending limb of the length converted catch curve was taken as the length at first capture (L_c). The length at first sexual maturity (L_m) *i.e.*, the length at which 50% of cuttlefishes reach their sexual maturity was estimated by fitting the percentage maturity against mid lengths. L_m was estimated as the point on X-axis corresponding to 50% point on Y-axis.

The total stock and standing stock (biomass) were estimated from the formula Y/U and Y/F respectively, while the maximum sustainable yield was estimated as MSY= 0.5 (Y/U). Relative yield per recruit (Y'/R) and relative biomass per recruit was estimated by using the model of Beverton and Holt (1966).

Results and discussion

Cuttlefish fishery in Oman

Cuttlefish are caught all over the coast of Oman from Oman and Arabian seas, but bulk of the catch comes from Arabian Sea (62%) (Fig. 2). They are exploited by both artisanal and industrial fisheries using different types of fishing gears (trawl, trammel nets, traps, hand and long lines).

The annual total cuttlefish catch landed along the Oman coast during the past 20 years from 1991 to 2011 showed great fluctuations (Fig. 3). The total catch fluctuated between a minimum of 700 t recorded in 1991 and a maximum of 8453 t in 2005. In 80's and early 90's, cephalopods were discarded in Oman, but in the recent past this fishery developed into a significant one and became a valuable resource attracting a net gross revenue of at least 11 million OR (OR ≈ 2.6$). Cuttlefish catch showed an increasing trend during 2003 to 2007, then drastically declined in 2009 and subsequently increased in 2010 and 2011 (Fig. 3).

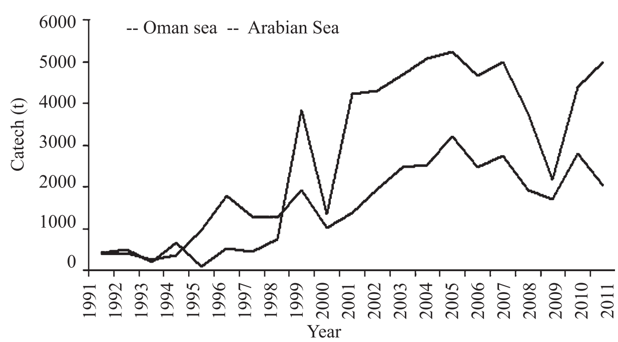

Fig. 2. Annual catch of cuttlefish from Arabian and Oman seas

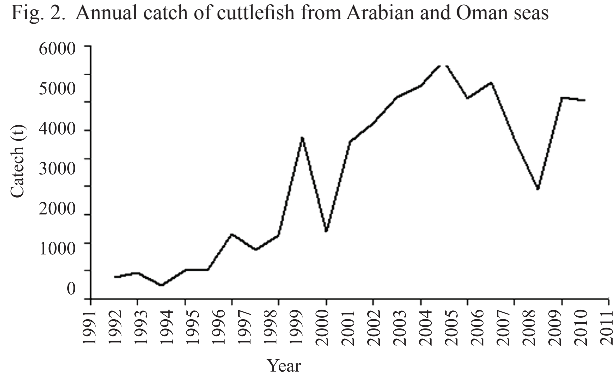

Fig. 3. Annual total catch of cuttlefish in Oman

Age determination

Age was determined based on length–frequency studies using the Bhattacharya's method (1967). It was possible to identify five distinct age groups or cohorts for *S. pharaonis*. The mean mantle lengths of sexes combined were 17.15, 28.89, 35.74, 39.91 and 42.53 cm for the 1st, 2nd, 3rd, 4th and 5th year, respectively. The most dominant age group was the first one representing 62.9%, while the other four age groups; II, III, IV and V represented only 27.2, 7.5, 2.1 and 0.3%, respectively.

Sanders (1981) reported that males of *S. pharaonis* grow to 34 cm mantle length by the end of three years while females grow to 31 cm in one year in Yemeni waters. Silas *et al*. (1985) reported lengths of 19.8, 28.1, 31.6 for females and 18.6, 27.7 and 32.2 cm ML for males by the end of 1st, 2nd and 3rd year, respectively in India. Nair *et al.* (1993) estimated the longevity as three years in India and reported lengths as 18, 27.4 and 32.3 cm for males and 19.2, 27.5 and 31.2 cm for females for the 1st, 2nd and 3rd year respectively. Abdul-Wahab (2003) found that both sexes grow to a maximum mantle length of 21 cm in the same area and the age may extend to three years for both sexes. Abdussamad *et al.* (2004) estimated the length at age data as 18.9, 26.8, 29.9 and 31.2 by the end of 1st, 2nd, 3rd and 4th year, respectively in India. Mehanna *et al.* (2009) reported the longevity of this species as three years with a mantle length range of 3.8-19.8 cm.

The differences between the values of longevity obtained in the present study and those of the previous studies can be attributed mainly to sampling which is considered as the main problem in using the length frequency data in age determination. Pharaoh cuttlefish in Omani waters showed higher growth rate than those from other localities and recorded higher mantle length in the area.

Mantle length - body weight relationship

A total of 4616 specimens (1895 males, 2051 females and 670 unsexed) were used to describe the ML-BW relationship. Males ranged in mantle length from 5 to 44 cm with weights ranging between 12 to 6000 g, while females ranged from 4 to 41 cm ML and from 9 to 5000 g in weight. The pooled data varied from 1.7 and 44 cm ML and from 3 to 6000 g body weight. The regression equations obtained from plotting BW against ML (Fig. 4) were:

Males : $W = 0.2402\ ML^{2.6714}$ ($r^2 = 0.984$)

Females: $W = 0.2256\ ML^{2.6953}$ ($r^2 = 0.977$)

Sexes combined: $W = 0.2616\ ML^{2.6412}$ ($r^2 = 0.9801$)

Analysis of residual sums of squares indicated no significant difference between the sex-specific length-weight relationships of *S. pharaonis* ($p > 0.05$). Estimated "b" values for *S. pharaonis* in the previous studies were found to be 2.58 and 2.75 for males and females respectively in Yemen (Sanders, 1981), 2.506 for males and 2.548 for females in India (Silas *et al.,* 1985); 2.60 for males and 2.629 for females in India (Nair *et al.,* 1993); 2.516 for sexes combined in the Arabian Sea (Al-Marzouqi *et al.,* 2009) and 2.743 and 2.829 for males and females respectively in the Gulf of Suez (Mehanna *et al.,* 2009). All results revealed an allometric growth for pharaoh cuttlefish as b is significantly different from 3.

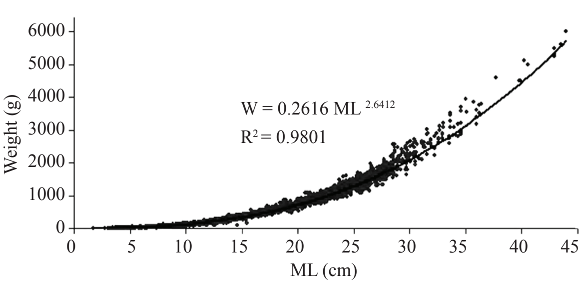

Fig. 4. Mantle length-weight relationship of *Sepia pharaonis* from Arabian Sea, Oman

Growth parameters

A likelihood ratio test (LRT) showed no significant difference between male and female VBGF growth curves, and hence the growth parameters were estimated for sexes combined. The mean mantle lengths obtained from Bhattacharya method were applied to the Gulland and Holt plot to estimate asymptotic length (L_∞), growth coefficient (K) and age at which the length is theoretically equals zero (t_o). The values obtained were $L_\infty = 46.21$ cm, $K = 0.52$ per year and $t_o = 0.1$ year. L_∞ and K values obtained from Powell-Wetherall plot (Fig. 5) were 46.65 cm and 0.6 per year, respectively. The estimated values obtained from ELEFAN I (Fig. 6) were $L_\infty = 46.8$ cm and $K = 0.62$ per year. All estimated values from the three methods showed a strong similarity, and so the values obtained from Gulland and Holt plot were chosen for subsequent calculations. The growth performance index ø' was estimated as 3.05.

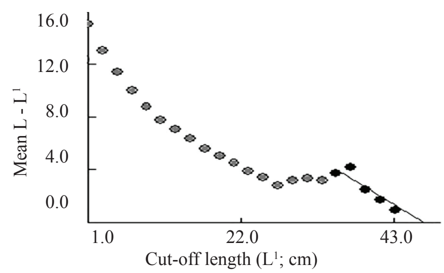

Fig. 5. Powell-Wetherall plot for *Sepia pharaonis* from Arabian Sea, Oman

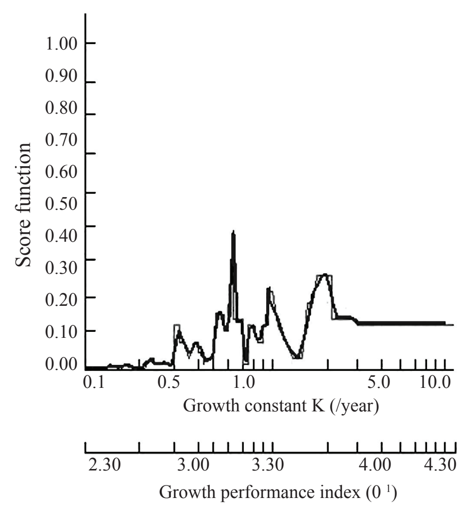

Fig. 6. K-scan using ELEFAN I program for *Sepia pharaonis* from Arabian Sea, Oman

Mortality estimates

The total mortality coefficient (Z) obtained from length converted catch curve analysis was 2.57 y^{-1} (Fig. 7). The natural mortality coefficient (M) calculated by Pauly's formula was 0.997 y^{-1}, while the estimated value of fishing mortality (F) was 1.57 y^{-1}. Exploitation rate (E) and exploitation ratio (U) were 0.61 and 0.66 respectively. The high values of both fishing mortality and exploitation rate reflect high level of exploitation. The higher level of exploitation in the present study can be attributed to the increased fishing effort targeting cuttlefish in the recent years. The only study which previously estimated the mortality and exploitation rates of pharaoh cuttlefish in the Arabian Sea was that of Al-Marzouqi *et al.* (2009). who estimated Z, M and F as 2.0, 1.52 y^{-1} and 0.48 y^{-1} respectively for data collected during 2001-2002. This indicates that the cuttlefish stock in the last 10 years is heavily exploited and impacted by the intensive fishing activities in Oman waters.

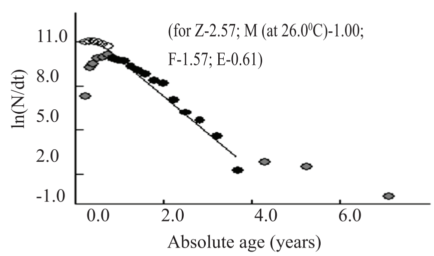

Fig. 7. Length-converted catch curve for *Sepia pharaonis* from Arabian Sea, Oman

Length at recruitment and length at first capture

The mid mantle length of the smallest length group in the catch (2 cm) of *S. pharaonis* was taken as an estimate of the length at recruitment (L_r), while the catch curve provided an estimate of L_c at 12 cm ML. The low values of L_r and L_c are indicators to overfishing, where they are caught before they grow large enough to contribute substantially to the stock biomass.

Length at first maturity L_m

The maturity ogives for *S. pharaonis* show that 50% of the catch were sexually mature at mantle length of 19.6 cm (Fig. 8). This means that the exploited *S. pharaonis* must be protected till the first 15 months of life in order to be able to spawn at least once and so a minimum size limit should be fixed for exploitation of the stock. Moreover, specific actions should be taken to conserve the spawning stock during August and December as well as during April and May being the active spawning seasons (Al-Marzouqi *et al.,* 2009).

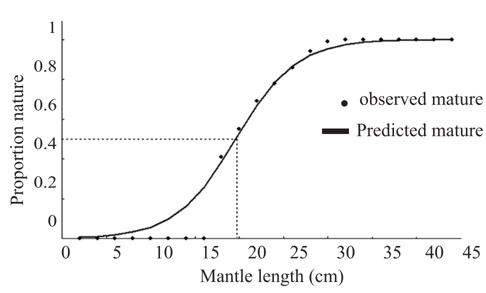

Fig. 8. Maturity curve for *Sepia pharaonis* from Arabian Sea, Oman

Maximum sustainable yield, stock and biomass

As estimated from Gulland equation, the maximum sustainable yield (MSY) from Arabian Sea was 4084 t, while the total stock was 8167 t and the standing stock (biomass) was 7542 t. The estimated MSY is lower than the current catch from the Arabian Sea (4989 t for 2011), which indicated the need for implementation of fisheries management regulations.

Relative yield per recruit (Y'/R)

Modeling and understanding cuttlefish exploitation is a challenge for a series of reasons such as life-cycle and population dynamics are different from those of finfish (Caddy, 1983; Boyle and Boletzky, 1996) , fishing is carried out by a range of gears and interacting fishing fleets, and cuttlefish distribution and abundance are influenced by environmental variation (Boletzky, 1983; Sobrino *et al.,* 2002; Wang *et al.,* 2003). The yield per recruit models are appropriate tools to get sufficient information about exploitation. The plot of Y'/R for *S. pharaonis* in the Arabian Sea against E (Fig. 9a) gives an estimate of present and optimum level of exploitation. It was found that, the present level of E (0.61) was higher than that which gives the maximum Y'/R (E=0.49) and to achieve the maximum Y'/R, the current level of exploitation should be reduced by 20%. For management purpose, the exploitation rate of *S. pharaonis* should be reduced from 0.61 to 0.29 (52%) to maintain sufficient spawning biomass.

To investigate the variation in Y'/R with changing of L_c which is related to the estimation of optimum mesh size, the Y'/R of *S. pharaonis* was calculated using $L_c \approx L_m$ = 20 cm (Fig. 9b). The results obtained indicated that the yield per recruit increases with increase of the length at first capture.

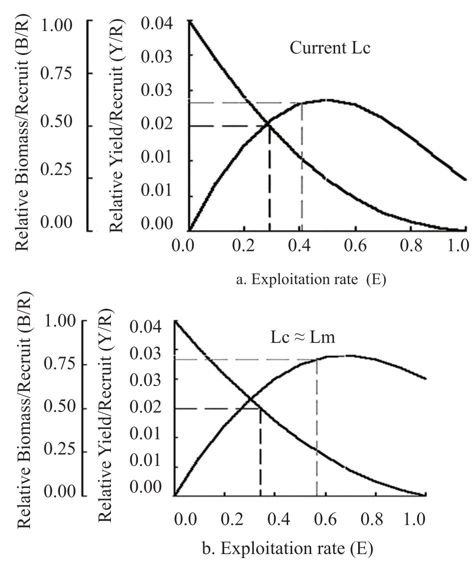

Fig. 9. Relative yield per recruit model for *Sepia pharaonis* from Arabian Sea, Oman

It can be concluded that *S. pharaonis* stock in the Arabian Sea is heavily exploited and to maintain this valuable resource, the present level of exploitation should be reduced by reducing the fishing effort. As the direct reduction of the fishing effort seems to be impossible for socio-economic reasons, proposing a closed season or a closed area especially during the spawning season will be an alternative option. Besides, increasing the length and age at first capture by increasing the mesh sizes would help to increase annual catches.

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