Int. J. Aquat. Biol. (2021) 9(2): 105-114
ISSN: 2322-5270; P-ISSN: 2383-0956
Journal homepage: www.ij-aquaticbiology.com

Original Article

Life history parameters of Yellowfin hind, *Cephalopholis hemistiktos* (Rüppell, 1830) in the coast of United Arab Emirates

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Abstract: The life history parameters, including age, growth, mortality and recruitment of Yellowfin hind, *Cephalopholis hemistiktos* were studied in monthly collected samples from January to December 2018. Otolith was used for age determination. Mean size by the end of each year of life was estimated and showed that, the highest annual increment was identified at the end of the first year of life then gradually decreased with increase of fish age. The estimated von Bertalanffy growth parameters were L_∞=43.51 cm, K=0.26 per year, t_0=-0.74 year. Asymptotic weight W_∞ was estimated as 1375.23 g. The length-weight relationship was $W=0.0126\ L^{3.0746}$ with R^2=0.94 for both sexes. The instantaneous rates of total mortality and natural mortality were estimated as 0.77 and 0.49 per year, respectively. The gonado-somatic index showed increasing from April to August with a peak in June for both sexes. Size at first capture *(L_c)* was estimated as 24.30 cm, which was smaller than the mean size at first sexual maturity 25.31 cm. The value of fishing mortality (F=0.28y^{-1}) was slightly higher than the optimum (F_{opt}=0.25y^{-1}) and smaller than the limit (F_{limit}=0.33y^{-1}) biological reference point, indicating that species was exploited within sustainable limit. Estimated parameters and the relative yield-per-recruit analysis showed that this species is not over-exploited.

Article history:
Received 5 January 2021
Accepted 20 Februry 2021
Available online 25 April 2021

Keywords:
Age
Growth
Mortality
Recruitment
Exploitation rate

Introduction

The fisheries of the United Arab Emirates are typically multi-species in nature with over 100 species being exploited (Grandcourt et al., 2010). They provide a source of income, employment and recreation contributing to the cultural heritage and food security of the inhabitants of the littoral states (Grandcourt, 2008). Groupers are of great importance in the marine ecosystems of all of the subtropical and tropical seas, and they play a basic role in the food chain, since they are one of the largest carnivores of the ecosystems (Grandcourt et al., 2009; Erisman et al., 2010; Craig et al., 2011). They are important to both commercial and recreational fisheries worldwide (Heemstra and Randall, 1999). Grouper populations have been depleted by overfishing, destruction of both juvenile and adult habitats, ineffective management plans for their fisheries or lack of any management policies (Sadovy et al., 2013). Grouper ecology is well-known in general, but detailed information on biological characteristics is scarce for many species. *Cephalopholis*, Bloch & Schneider is the most common genus of the family Serranidae in the aquarium trade and some species of this genus feature colorful bodies (Abied et al., 2014). The genus comprises 22 species (FAO, 2002), of these, *C. hemistiktos* is one of the most abundant species that have a disjunctive distribution, being known with certainty only from the northern part of the Red Sea to the Coast of the Pakistan (Randall, 1995). *Cephalopholis hemistiktos* is primarily caught using traps, and to a lesser degree hand lines (Hartmann, 2013). In the Emirates fisheries, *C. hemistiktos* has a minor components of the demersal species and represents 3.30% of the secondary commercial species caught by traps (Farrag et al., 2020). Due to the scarcity of published information on *C. hemistiktos*, this study was carried out to shed the light on the its

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DOI: https://doi.org/10.22034/ijab.v9i2.1089

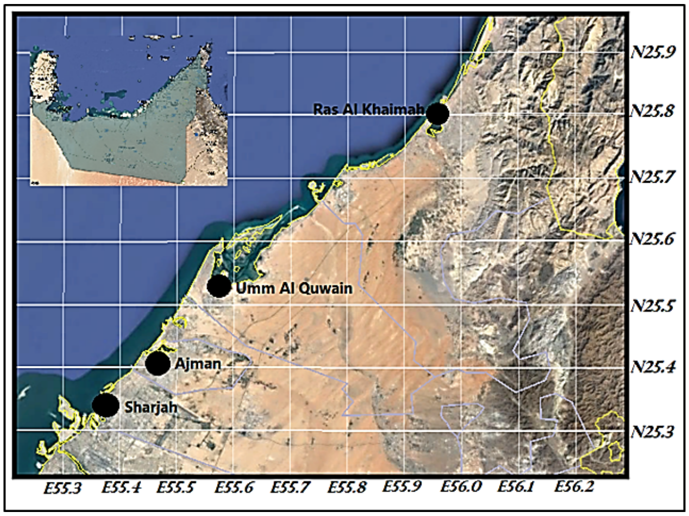

Figure 1. Map showing the sampling sites.

life history and provide its status assessments as one of the subordinate species in the United Arab Emirates fisheries.

Materials and Methods

Study area and samples collection: Monthly size frequency data and biological samples were collected from four locations along the Coast of the United Arab Emirates namely Ras Al-Kheima, Umm Alqwain, Ajman and Sharjah from January to December 2018 (Fig. 1). Fishes were mainly captured by traps and selected random from landings.

Age and growth parameters: Total length was recorded to the nearest mm by measuring board. Whole wet weight was measured with an electronic balance and recorded to the nearest g. The sex was determined by macroscopic examination of the gonad, which was removed and weighed to 0.1 g with electronic balance. Sagittal otoliths were extracted, cleaned, dried, weighed to 0.1 mg. One of each pair of sagittae embedded in epoxy resin and transverse sections through the nucleus were obtained using a twin blade saw. Sections were mounted on glass slides and examined using a low power microscope and transmitted light. Two different observers recorded the number of alternating opaque and translucent bands. The counts of the two observers were then compared, and any that differed by more than one zone were removed from further analysis.

Parameters of the length-weight relationship were estimated by fitting the power function to length and weight data according to the equation $W=a*L^b$ (Ricker, 1975), where W is the wet weight, a is a constant, L is the total length and b is close to 3.0 for species with isometric growth. In order to verify if calculated b was significantly different from 3, the Students t-test was employed (Froese, 2006). Fatness of fish was described by calculating the coefficient of condition (Fulton, 1904) from the formula $K=100*W/L^3$ where W is the total weight in g and L is the total length cm. Growth was investigated by fitting the von Bertalanffy growth function (von Bertalanffy, 1938) as follows: $L_t=L_\infty*1\text{-}exp^{-K\ (t-t_o)}$, where L_t is length at age t, L_∞ is the asymptotic length, k is the growth coefficient and t_o is the hypothetical age at which length is equal to 0. The parameters of von Bertalanffy were estimated according to Ford (1933) and Walford (1946), and age at length 0 was calculated using empirical formula (Pauly, 1984). Growth performance index $\emptyset=LogK+2logL_\infty$ and $\emptyset=K+2/3logW_\infty$ for length and weight, respectively was calculated according to Pauly and Munro (1984). The potential longevity T_{max} was estimated based on the formula of Beverton (1992) as $T_{max}=3/K$.

Reproductive biology: Gonado-somatic index (*GSI*) was calculated using the following equation according to Anderson and Gutreuter (1983): $GSI=100*\ W_t/W_G$, where W_t is the gonad weight and W_G is the gutted weight g. Sex ratio and its percentage was estimated as the number of females to the number of males in the catch, the significant differences from the theoretical ratio (1:1) were tested by Chi-squared test X^2. The mean size (L_m) at first sexual maturity was estimated by fitting the logistic function to the proportion of mature fish in 10.0 mm size categories (King, 1995). The corresponding age at first sexual maturity was estimated based on Froese and Binohlan (2000). Juvenile retention was calculated as the proportion of fish in landings that were below the mean size at first maturity.

Fisheries assessment and Per-recruit analysis: The annual instantaneous rate of total mortality (Z) was determined using methods of length converted catch curve (Pauly, 1983) and linearized catch curve

Table 1. Length-weight relationship of *Cephalopholis hemistiktos* for males, females and sexes combined.

Sex	No.	TL* range (cm)	TW* range (g)	a	b	R^2	Growth type	Average K*
Male	67	18.0-41.0	92.0-999.00	0.0095	3.1568	0.9635	Isometric	1.58
Female	511	16.0-42.0	69.0-1251.0	0.0132	3.0621	0.9413	Isometric	1.61
combined	578	16.0-42.0	69.0-1251.0	0.0126	3.0746	0.9444	Isometric	1.60

* TL: total length, TW: total weight, K: condition factor

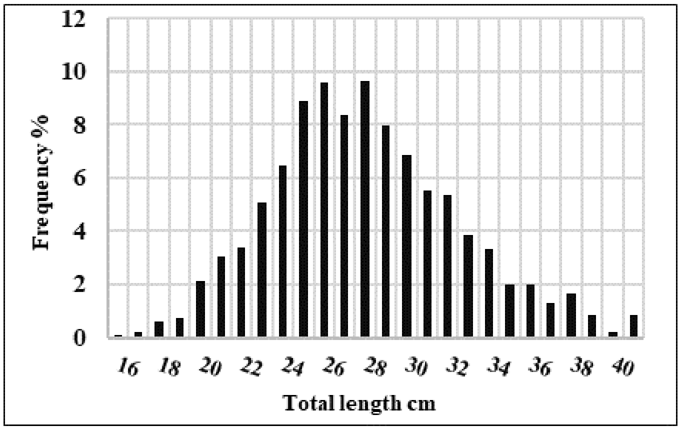

Figure 2. Length frequency distribution of *Cephalopholis hemistiktos*.

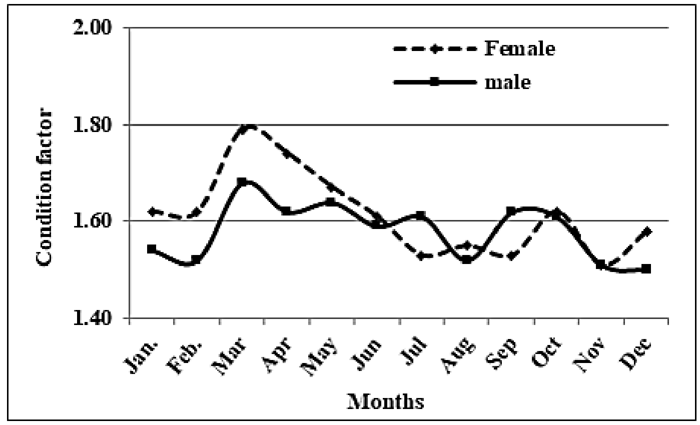

Figure 3. Monthly changes in values of condition factor for *Cephalopholis hemistiktos*.

(Ricker, 1975) and the mean rate of the total mortality was used for further analysis. Backwards extrapolation of length converted catch curve were used to determine probability of capture (L_c) and the corresponding age at first capture (t_c) was estimated based on Beverton and Holt (1957).

The mean annual natural mortality *(M)* was calculated by three different methods according to Rikhter and Efanov (1976), Pauly (1980) and Hoening (1983). Fishing mortality was estimated from the equation $F=Z–M$. The biological reference point *BRP* was estimated by the formula of Patterson (1992) as $F_{opt}=0.5*M$ and $F_{limit}=2/3*M$. The exploitation rate *E* was calculated as the proportion of the fishing mortality relative to total mortality $E=F/Z$ (Gulland, 1971).

The exploitation rate producing maximum yield E_{max}, the exploitation rate at which the marginal increase of *Y'/R* is 10% of its virgin stock $E_{0.1}$ and the exploitation rate which the stock is reduced to 50% of its unexploited biomass ($E_{0.5}$) were estimated. The relative yield per recruit *Y'/R* and relative biomass per recruit *B'/R* were calculated using the model of (Beverton and Holt, 1966) and modified by Pauly et al. (1996).

Results

Age and growth: A total of 1504 length frequency samples were collected ranging 16.0-42.0 cm and the length groups of 25, 26, 27 and 28 cm were the most frequent in the catch while the terminal length groups of 16, 17 and 41 cm were the least frequent ones (Fig. 2). A total of 578 *C. hemistiktos* were used to estimate the length weight relationship (511 females and 67 males). The relationship between fish total length and total weight of male, female and sexes combined shows in Table 1. The t-test analysis showed a non-significant difference ($t<t_{critical}$ at *CI* 95%), which reflect that growth is isometric. The high values of regression coefficient (R^2) indicate that the correlation of total length is best described by linear regression equations.

The maximum values of condition factor for males (1.68) and females (1.79) were observed in March i.e. before the maturation of gonads. While the minimum values (males: 1.50, females: 1.51) were recorded in December and November, respectively i.e. after the spawning season. In general, the average condition

Table 2. Back calculated lengths at the end of each year of life as well as the annual increment of *Cephalopholis hemistiktos*.

Age group	No.	Observed length	Back calculated lengths at the end of each year of life						
			I	II	III	IV	V	VI	VII
I	42	17.3	18.03						
II	89	24.21	17.43	25.02					
III	152	28.12	17.02	24.60	29.82				
IV	76	32.26	16.47	23.13	28.02	32.22			
V	36	35.19	16.12	22.26	27.89	32.04	35.04		
VI	16	37.91	15.90	21.23	26.80	31.16	34.12	37.16	
VII	7	39.98	15.23	20.80	26.13	30.29	33.06	35.12	38.05
Mean			**16.60**	**22.84**	**27.73**	**31.43**	**34.07**	**36.14**	**38.05**
Increment			16.60	6.24	4.89	3.70	2.65	2.07	1.91
Increment%				37.59	29.47	22.26	15.94	12.45	11.51

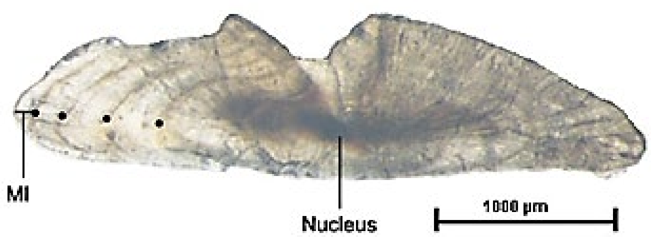

Figure 4. Sectioned sagittal otoliths of *Cephalopholis hemistiktos* ((4 annual rings) 32.2 cm TL). MI is the marginal increment).

factor of females was higher than males (Fig. 3).

A subsamples of 468 *C. hemistiktos* were aged using sagittal otolith using transmitted light under low power magnification (Fig. 4). Two independent readers agreed on the age of 89.0% (418/468). Otolith radii were found to be directly proportional and correlated with total length of *C. hemistiktos* L=0.0089OR+9.581 (r=0.94). The back calculated size at age showed that this species attains length at the end of each year from 1st to 7th year as follows: 16.60, 22.84, 27.73, 31.43, 34.07, 36.14 and 38.05 cm, respectively (Table 2). The catch was characterized by lacking of juvenile stage (Age group 0). The annual growth rate was rapid in the first year (37.59%), then gradually decrease with increasing in to reach 1.91% in 7th year. The most dominant age group in the catch was the 3rd year forming 36.36%, while the last age group (7th year) represent 1.67%.

Parameters of the von Bertalanffy growth function were estimated as: K=0.26, L_∞=43.51 cm and t_o=-0.74 years for combined sex. The value of W_∞ was obtained by applying the length weight relationship as 1375.23 g.

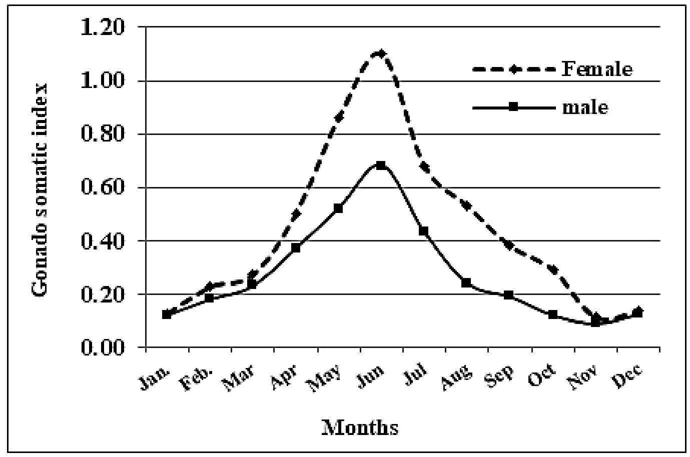

Figure 5. Mean monthly gonado-somatic index for *Cephalopholis hemistiktos*.

The growth performance index Ø was found to be 2.70 for growth in length and 2.36 for growth in weight. The theoretical growth in length of the whole population of *C. hemistiktos* can be expressed as: L_t= 43.51*[1-exp(-0.26*(t+0.74))]. The theoretical growth in weight (the combination between von Bertalanffy and length-weight relationship equations) of the whole population of *C. hemistiktos* was as: *Wt* = 1375.23*[1-exp(-0.26*(t+0.74))]$^{3.0746}$. The longevity of *C. hemistiktos* was estimated to be 11.5 years.

Reproductive biology: The monthly GSI of male and female are given in Figure 5. The mean monthly GSI fluctuated 0.09-0.68 and 0.11-1.10 in Novembers and June for male and female, respectively. The GSI increased from April to August with a peak in June for both sexes. The ratio of males to females was 1.0: 8.0 and the X^2 goodness of fit tests indicated that *C. hemistiktos* had significantly female biased sex

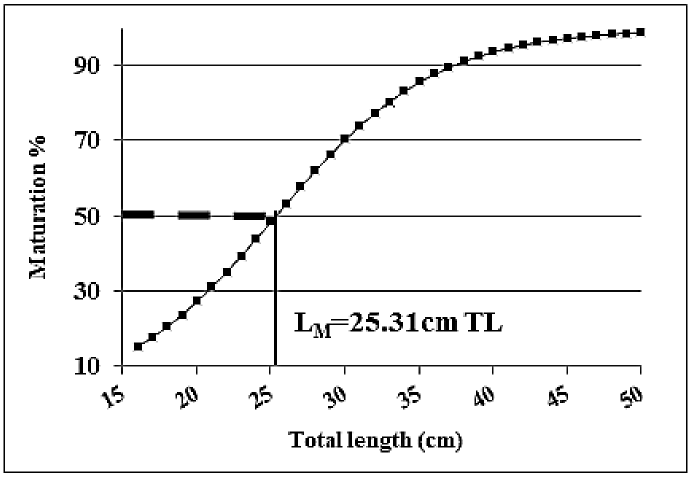

Figure 6. Length at first sexual maturity (LM) for *Cephalopholis hemistiktos*.

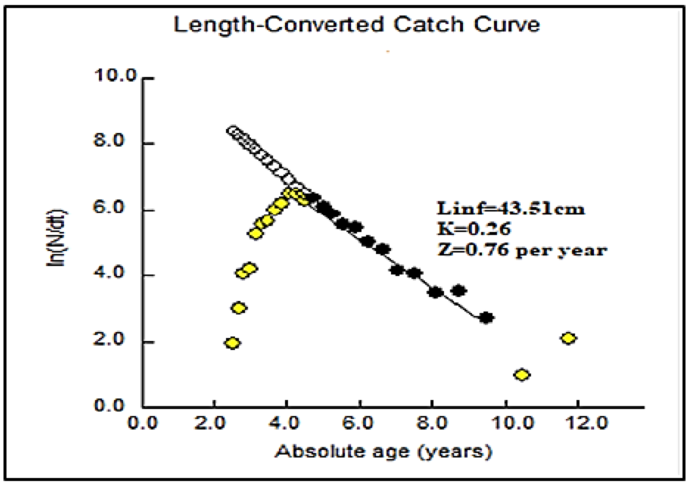

Figure 7. Length converted catch curve of *Cephalopholis hemistiktos* K=0.26y-1, L∞= 43.51 cm.

ratio (X^2=52.62, P<0.05). Size at first sexual maturity was estimated as 25.31 cm and the corresponding age was 2.55 years (Fig. 6). The proportion of immature fish in aggregated size frequency samples that were below the mean size at first sexual maturity (Juvenile retention rate) was 32%. The recruitment pattern of *C. hemistiktos* shows defined peaks in recruitment to fishery in May and August (14.27 and 12.84%, respectively).

Mortality estimation and fishery assessment: The length converted catch curve (Fig. 7) gave the total mortality coefficient (Z=0.76; *CI* 95% of Z=0.68-0.83y^{-1}) close to that estimated with linearized catch curve (Z=0.77y^{-1}). Thus the mean value of total mortality 0.765y^{-1} was chosen for further analysis.

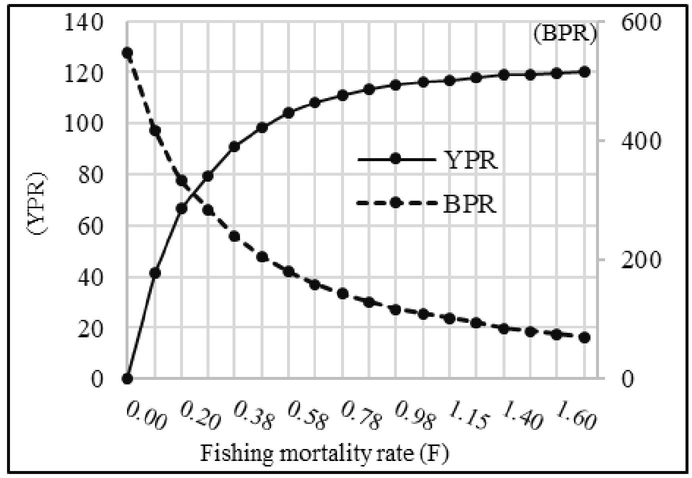

Figure 8. Yield per recruit and biomass per recruit curves of *Cephalopholis hemistiktos* (F=0.28year^{-1}; M=0.49 and T_c=2.35years.

The mean value of the natural mortality coefficient (M) estimated based on the three applied methods was 0.49y^{-1} and the survival rate was 0.47y^{-1}. The length at first capture (length at 50% capture) was estimated as 24.30 cm, which was smaller than the mean size at first sexual maturity. The corresponding age at first capture was calculated as 2.35 years. The length and age at first recruitment (*Lr* & *Tr*) were estimated as 16.0 cm and 0.99 years. The values of Z and M gave a value of fishing mortality F=0.28y^{-1}, slightly higher than the optimum (F_{opt}=0.25y^{-1}) and smaller than the limit (F_{limit}=0.33y-1) biological reference point. The exploitation rate is very important to estimate the state of the stock whether optimum, underexploited or overexploited.

The exploitation rate for *C. hemistiktos* was 0.36 which is less than the optimum (E=0.5) given by Gulland (1971). Figure 8 shows the yield per recruit and biomass per recruit of *C. hemistiktos*. At the current level of fishing mortality and age at first capture, the yield per recruit and biomass per recruit were estimated as 79.66 and 284.50 g, respectively.

Based on the results, the increasing of fishing mortality at the current level of age at first capture will increase the *YPR* to reach the maximum while the *BPR* will decrease. The relative spawner biomass per recruit was estimated as 52.35% of the theoretical unexploited level at the existing fishing mortality rate, indicating species was exploited within sustainable

Table 3. Biogeographic comparison of VBGF parameters (*Cephalopholis* species).

Author	**Location**	**Species**	**L_∞**	**K**	**T_o**
Potts & Manooch, 1999)	South-eastern coast of USA	*C. cruentata*	38.50	0.32	0.49
		C. fulva	44.60	0.13	-1.15
Wahbeh, 2005	Gulf of Aqaba, Jordan	*C.miniata*	58.65	0.08	-1.84
AraÙjo & Martins, 2006	Central Coast of Brazil	*C. fulva*	31.60	0.14	-5.74
Mohammad, 2007	Red sea	*C.argus*	52.60	0.16	-1.41
Grandcourt el al., 2013	United Arab Emirates (Abu-Dhabi)	*C. hemistiktos*	26.20	0.14	-10.9
Tarich et al., 2015	Cape Verde Archipelago	*C.taeniops*	54.26	0.14	-0.85
Mehanna et al., 2019	Hurghada Red Sea Coast	*C.argus*	44.22	0.26	1.33
Present study	United Arab Emirates	*C.hemistiktos*	43.51	0.26	-0.74

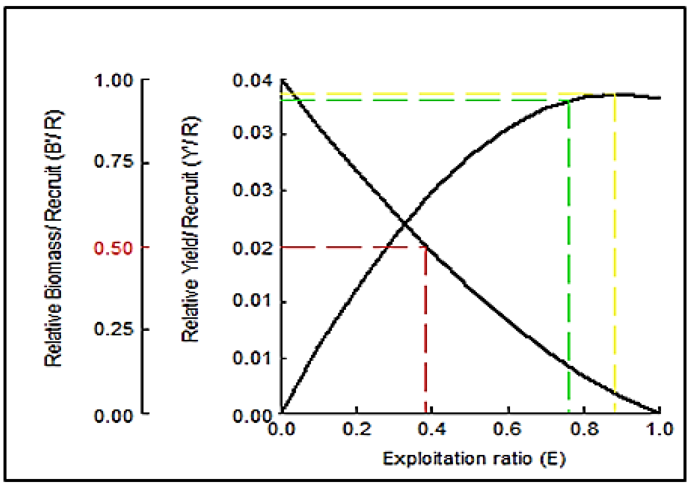

Figure 9. Relative yield per recruit and relative biomass per recruit of *Cephalopholis hemistiktos* (*M/K* = 1.88; L_c/L_∞=0.56; E_{max}= 0.88; $E_{0.1}$ = 0.76; $E_{0.5}$ = 0.38).

limit. Estimates of relative yield per recruit and relative biomass per recruit as graphically represented in Figure 9. The values of E0.1, E0.5 were 0.76 and 0.38, respectively, higher than the current level of exploitation rate (*E*=0.36).

Discussions

In all studies performed on species of the genus *Cephalopholis*, it is necessary to use otolith for ageing (Chan and Sadovy, 2002; Araùjo and Martins, 2009). Sagittal otolith of *C. hemistiktos* grow proportionally through the life of fish as seen in other *Cephalopholis* species (Trott, 2006; Araùjo and Martins, 2006, 2009). Almost all tropical epinephelids and all *Cephalopholis* species lay down increments annually (Craig et al., 1999; Potts and Manooch, 1999; Chan and Sadovy, 2002; Bustos et al., 2009; Choat et al., 2009). The oldest fish found in this study was 7.0 years old similar to *C. boenak* and *C. miniata* (9 years) in Gulf of Aqaba, Jordan (Wahbeh, 2005); *C. urodeta* (10 years); *C. spiloparaea* (7 years); *C. sexmaculata* (8 years) and *C. argus* (5 years) in Papua New Guinea (Fry et al., 2006); *C. argus* (6 years) in Red Sea Coast (Mehanna et al., 2019). However, the maximum age observed differs substantially from what was described for *C. hemistiktos* in Jamaica where specimens of up to 26 years were found (Mathews and Samuel, 1987); *C. panamensis* in Mexico (14 years) (Craig et al., 1999); *C. fulva* in Brazil (25 years) (Araùjo and Martins, 2006, 2009); *C. taeniops* (20 years) in Cape Verde Archipelago.

This study indicated that *C. hemistiktos* in the United Arab Emirates is slightly fast growing species (K=0.26 year^{-1}). This is different from that reported by Grandcourt et al. (2013) in Emirate of Abu-Dhabi (*K*=0.14), while similar to the result of Mehanna et al. (2019) (*K*=0.26 for *C. argus*). Negative T_o is common in species that grow rapidly in the first year, and slowly later in life (Sadovy et al., 1992; Craig et al., 1997). In the present study, the T_o was negative, as other works on this genus (Craig et al., 1999; Potts and Manooch, 1999; Araùjo and Martins, 2009). Asymptotic length (L_∞) was estimated as 43.51 cm similar to *C. fulva* (Potts and Manooch, 1999) and *C. argus* (Mehanna et al., 2019). Table 3 shows a comparison between the von Bertalanffy growth parameters estimated by other authors for *Cephalopholis* species and this study. The variation between growth coefficient may be due to different localities, methods used, environmental condition, fish maximum length and number of samples.

(Wahbeh, 2005; Araùjo and Martins, 2006 and Tarich et al., 2015).

In the present work, Ø of *C. hemistiktos* was similar to *C. argus* in Red Sea (Mehanna et al., 2019) and lower than *Cephalopholis* species in Red Sea (2.93) (Mohammad, 2007). The growth performance index estimated by us was higher than that estimated by Wahbeh (2005) in Gulf of Aqaba (2.27). Comparison with other species of groupers, Ø falls within the range 2.11-2.65 as reported for species of *Cephalopholis* (Matheson and Huntsman, 1984; Mathews and Samuel, 1987; Chan and Sadvoy, 2002).

In the present study, the b-value was estimated as 3.0746 which is similar to *C. hemistiktos* (3.042) and *C. argus* (3.038) (Grandcourt et al., 2013; Mehanna et al., 2019). Wahbeh (2005) stated the length-weight relationship showed allometric growth in females and isometric in males of *C. miniata*. According to Bennet (1970), Fulton's condition factor ≥0.56 considered as well-being bench mark values of a fish, hence fishes with condition factor values above the well-being bench mark were considered to be in good condition.

Spawning in groupers tends to be restricted to less than half the year, with many species spawning primarily during 1 to 2 months (Shapiro, 1987). In the present study, the GSI and maturity stage data suggest the spawning period in the spring-summer seasons, starting in April and ending in August. Grandcourt et al. (2013) declared two peaks of GSI of *C. hemistiktos*, during the May to August and October to November. The present study agrees with spawning seasons reported for groupers from elsewhere (Manickand-Heilman and Philips, 2000; Mackie, 2000; Chan and Sadvoy, 2002). The ratio of males to females was 1.0: 8.0 and the X^2 goodness of fit tests indicated that *C. hemistiktos* has significantly female biased sex ratio.

In the present work, the total mortality was 0.77year^{-1} compared to the double value of *Z* reported by Grandcourt et al. (2013). The annual instantaneous rate of Z may have been overestimated if larger fish were less vulnerable to the fishing gear or if adult fish underwent migrations for example. For *C. argus*, the total mortality was estimated as 1.88 and 1.31year^{-1} in Red Sea (Mohammad, 2007; Mehanna et al., 2019, respectively). Our estimate of the natural mortality rate derived from different methods was 0.49 year^{-1} which is higher than that estimated by Mohammad (2007) and Grandcourt et al. (2013) where the values were 0.44 and 0.21year^{-1} for *C. argus* and *C. hemistiktos*, respectively. While the current *M* was lower than that estimated by Mehanna et al. (2019) (0.56year^{-1}).

As the size at first capture (24.30 cm) was smaller than the size at first sexual maturity (25.31 cm) and the size at which yield per recruit would be optimum (L_{opt}=26.91 cm), an increase in the mesh size for the trap fishery should be considered by management authorities. This is particularly important given that 32% of the yield in numbers consisted of fish that were below the size at first sexual maturity. If fish were retained by traps at the size at which yield per recruit would be optimum (26.91 cm), they would have a chance to spawn at least one time before reaching the mean size at first capture.

The use of yield per recruit models may be particularly restrictive for fast growing tropical species with high rates of natural mortality as the curves may not reach a maximum within a reasonable range of fishing mortality values (Gayanilo and Pauly, 1997). The result of the present study indicated that, with the increasing of fishing mortality and at the current level of age at first capture, the *YPR* increased to reach the maximum while the BPR will decrease. The relative yield per recruit analyses indicated that an increase in the size at first capture to that which would maximise yield per recruit would be associated with an increase in yield at the existing fishing mortality rate. The specified precautionary target (F_{opt}=0.5*M) and limit (F_{limit}=2/3*M) values are more appropriate biological reference points in light of the constraints of the yield per recruit model. In the present work, the value of fishing mortality i.e. F=0.28y^{-1} was close to the optimum (F_{opt}=0.25y^{-1}) and smaller than the limit (F_{limit}=0.33y^{-1}) biological reference point, indicating that species was exploited within sustainable limit.

In conclusion, the present study gave the life history parameters (age, growth and mortality) of subordinate species *C. hemistiktos* and provide more details about the impact of fishing gear on the demersal species, and suggest that, both reduction in fishing effort and mesh size regulations will be required for the demersal trap fishery.

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