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Age, growth, mortality, and exploitation rate of blueline snapper, *Lutjanus coeruleolineatus* (Actinopterygii: Perciformes: Lutjanidae), from Dhofar Governorate, Sultanate of Oman

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Abstract

The blueline snapper, *Lutjanus coeruleolineatus* (Rüppell, 1838), is a significant commercial fish species harvested from the traditional fishery in the Sultanate of Oman. Deficient data on this species, however, make the management strategies challenging, especially in fisheries ecology. A total of 978 specimens were obtained from Dhofar Governorate off the coast of the Arabian Sea during the period between February 2015 and March 2016. In total, 296 sectioned otoliths were analyzed and growth was estimated from non-seasonal growth by using von Bertalanffy method. The parameters of von Bertalanffy growth function, total mortality (Z), natural mortality (M), fishing mortality (F), and exploitation rate (E) were determined and compared with those for Lutjanidae fishes elsewhere. The age structure of male fishes was between 1 and 14 years for males while the age of females ranged from 1 to 18 years. Growth rate (K) was 0.21 y^{-1} and 0.16 y^{-1} for males and females, respectively. The hypothetical length of female (L_∞ = 46 cm) was relatively higher than that of male (L_∞ = 42 cm). The natural mortality (M) was 0.296, total mortality (Z) was 0.372, fishing mortality was 0.076, and exploitation rate (E) was estimated as 0.2. The presently reported study is conducted to examine this fish in relation to growth parameters by analyzing otolith structure. The results of the presently reported study will contribute towards planning the regional fishery management policies in Oman.

Keywords

Arabian Sea, blueline snapper, Dhofar, exploitation rate, mortality, otolith

Introduction

Fishery resources are one of the greatest marine resources in the Sultanate of Oman and have been extensively helping fishermen for their livelihood (Al-Marzuqi 2011). The total landing of artisanal, coastal, and industrial fishery, as well as its aquaculture in the Sultanate of Oman, raised from 211 000 t with a value of about US $ 166 million in 2014 to 580 000 t with a value of about US$ 795 million in 2019. Oman's coastal regions are surrounded by three bodies of water, including the Arabian Sea, the Sea of Oman and, the Persian Gulf. The country is rich in

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biodiversity of marine resources and possesses a 3165 km long coastal line (Al-Anbouri et al. 2013). The fisheries in the Sultanate of Oman constitute a variety of commercially important marine species that support the artisanal fisheries sector and industrial fleet. In addition, the seafood trade and related industries have investment opportunities that help to grow and sustain the income of the fishermen (Al-Abdessalaam 1995).

The blueline snapper, *Lutjanus coeruleolineatus* (Rüppell, 1838) (hereafter blueline snapper), is a member of the family Lutjanidae which contains 17 genera and about 113 species (Froese and Pauly 2019). There are five species of the genus *Lutjanus* characterized by yellowish body color with 4 to 8 blue longitudinal stripes (Barman et al. 2014). Such snappers include *Lutjanus bengalensis* (Bloch, 1790), *Lutjanus kasmira* (Forsskål, 1775), *Lutjanus notatus* (Cuvier, 1828), *Lutjanus quinquelineatus* (Bloch, 1790), and *Lutjanus viridis* (Valenciennes, 1846) (see Allen 1985). However, *L. coeruleolineatus* can be distinguishable from other species of the genus by yellow body, darker on back and whitish ventrally with distinguished blue elongated stripes (7–8) on the sides, a large black spot on the lateral line, and the fish head has blue spots and broken lines (Randall 1995). It is commonly known as snappers and it is also called 'Neissar' and/or 'Qalaya' in Oman. The species is properly common and is frequently found at a fish market and landing sites. It is mainly caught with handlines, traps, and gillnets (Al-Abdessalaam 1995).

The presently reported study was conducted to analyze the stock assessment parameters of blueline snapper, *Lutjanus coeruleolineatus*, using otolith microstructure. Furthermore, the presently reported study attempted to determine the growth parameters based on males and females of blueline snapper that can reveal signs of exploitation level. Such data clarify the state of the stock which can be then used by decision makers to manage and control the exploitation of the stock of blueline snapper for sustainability over time. Hence, an essential study on the age and growth of this species is required to understand their longevity and growth rate in the Arabian Sea.

Materials and methods

Samplings and laboratory works

In total, 978 specimens of blueline snapper were landed by gillnets and handlines from Salalah Fish Market (SFM) (17°01.2′N, 54°04.58′E) at Dhofar Governorate from March 2015 to February 2016. Among the samples collected, randomly selected 296 fish (158 females and 138 males) were used for age determinations using sagittal otolith. A pair of otoliths (Fig. 1) were removed from each specimen. The sagitta was mounted on a glass slide using epoxy resin (Brothers et al. 1983). The otolith was then grounded and Isomet low-speed diamond saw was used to make 200–300 µm thick transverse sections of sagittal otoliths containing the core of the otolith (Cowan et al. 1995). The sections were examined under a stereomicroscope using both reflected and transmitted lights. The fish ages were determined by counting annuli which consist of an opaque and translucent ring. The opaque zones were observed with reflected light while the translucent rings were observed in transmitted light. All counts were made by two readers, repeated at least two times, and then appropriate readings were selected. Sectioning otoliths were reading and determine the age based on counting the number of opaque rings along the dorsal edge of the sulcus acoustics (Allman et al. 2005). For instance, otolith with three completed annuli and a large translucent zone will be classified as 4 age.

Estimation of growth parameters

The growth parameters of blueline snapper were estimated as a relation between body size and age the non-seasonal von Bertalanffy growth function (Ricker 1975) using below the formula:

$$L_t = L_\infty \times (1 - e^{K(t - t0)})$$

where L_t is length of fish at age t, L_∞ is the hypothetical length, K is the instantaneous growth coefficient and t_0

Figure 1. A pair of sagittal otoliths for blueline snapper, *Lutjanus coeruleolineatus*.

is the hypothetical age at which length is equal to 0. The growth parameters of sex's pooled, male and female data were fitted using the Vonbitb program (Stamatopoulos and Caddy 1989) with solver parameters to reduce the residual sum of squares.

The longevity (life span) was estimated by (Pauly 1983) formula to estimate maximum size at age:

$$t_{max} = 3K^{-1}$$

where t_{max} is the longevity and K is the instantaneous growth.

Age validation

In order to validate if the opaque and hyaline zone are laid annually, the marginal increment analysis of the otoliths was investigated following Lessa et al. (2006):

$$\text{MIR} = (R_C - R_L) \times (R_L - R_{L-1})^{-1}$$

where MIR is the marginal increment ratio, R_C is the otolith radius from the primordium to the edge, R_L is the otolith radius from the primordium to the last annulus, and R_{L-1} is the otolith radius from the primordium to the annulus next to the last one.

The mean marginal increment ratio was calculated monthly and plotted to examine if the annuli of the otolith formed annually or not and to estimate the translucent ring growth (slow–fast) during the year.

Mortality and exploitation rate

The annual instantaneous rate of mortality (Z) was estimated using the length converted catch curve method (Pauly 1983) and Beverton–Holt method (Beverton and Holt 1957) employed by LFDA5 program (Kirkwood et al. 2003). The fishing mortality (F) was calculated following Pauly (1980):

$$F = Z - M$$

Natural mortality (M) was estimated from the empirical equation using temperature and growth parameter K (Pauly 1980) described by:

$$\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T$$

where the T value was taken as 24°C as this value represented the mean bottom water temperature in the Arabian Sea of Oman (Thangaraja 1995). The natural mortality (M) also was measured based on longevity (Alagaraja 1984; Hoenig 1984; Hewitt and Hoenig 2005) and growth parameter K (Jensen 1996).

The exploitation rate can be defined as the proportion of harvestable-sized fishes that are removed from a population annually through different fishing activities (Meyer and Schill 2014). The exploitation rate (E) was calculated by using Sparre and Venema (1992) equation:

$$E = F \times Z^{-1}$$

where E is the exploitation rate, F is the fishing mortality, and Z is the annual instantaneous rate of mortality.

Results

Length frequency

Total lengths (TL) of all blueline snapper sampled ranged from 19.4 to 43.7 cm with a mean of 28.4 cm (±0.14). Among them, 529 female and 449 male (sex ratio of F:M = 1.18) specimens were determined, females ranged from 20.4 to 43.7 cm TL with a mean of 29.1 cm (±0.21), which was significantly longer than the mean TL of males (27.5 ± 0.16 cm, $t_{0.05,\,df=976} = -5.63$, $P < 0.05$).

Analysis of the length distribution for blueline snapper revealed that the majority of specimens (male and female) were concentrated at length classes between 26 cm TL and 36 cm TL. However, lengths classes less than 26 cm TL and bigger than 36 cm TL were recorded by few specimens (Fig. 2).

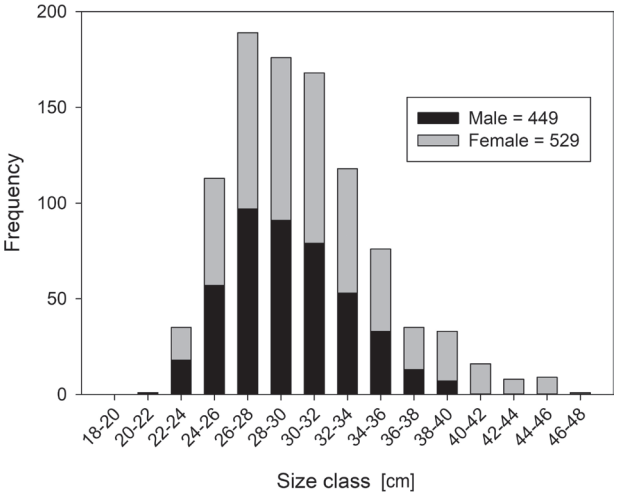

Figure 2. Length frequency distributions (cm, TL) for male and female blueline snappers, *Lutjanus coeruleolineatus* sampled from Dhofar Governorate.

Age and growth

The rings were clearly visible with a high level of readability (90%) and the age of the fish could be determined in the majority of them.

The size of blueline snapper to age data were fitted for each sex separately by using the non-seasonal von Bertalanffy growth function (VBGF) in order to estimate the growth pattern of this species (Fig. 3). The age structures

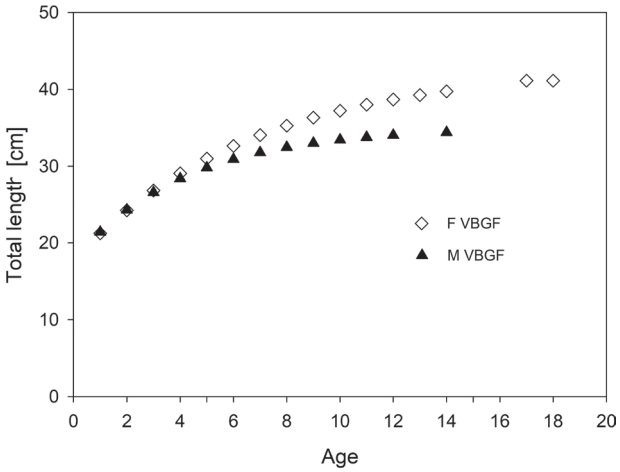

Figure 3. VBGF curves for male and female(n = 158) and male (n = 138) blueline snapper, *Lutjanus coeruleolineatus*.

estimated by otolith annuli analysis of blueline snapper ranged from 1 to 14 years for males and 1 to 18 years for females. Age distributions at each length class for male, female, and all sex combined were illustrated in Tables 1, 2, and 3, respectively. Overall, the majority of the individuals were below age 15 (Only 3 individuals had the age upper 15 years, with one specimen showing the oldest age of 18 years; Table 3). The von Bertalanffy growth function (VBGF) suggests that the male fish had a higher growth rate (K = 0.21 y^{-1}) than female. While, the hypothetical length of the female (L_∞ = 46) was significantly higher than that of male (27.6 ± 0.33 cm, $t_{0.05,\,df=296}$ = 3.01, P < 0.05). The age estimation indicates the life spans (t_{max}) are 14.2, 18.7, and 17.6 years for male, female, and combined sexes, respectively.

Table 1. Age–length key of *Lutjanus coeruleolineatus* males from Dhofar Governorate, Sultanate of Oman.

TL [cm]	Age [year]														Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
18–20															0
20–22	1	5													6
22–24	3	15	2												20
24–26	8	9	11		1										29
26–28		11	6	4	2										23
28–30		2	4	8	6	1		1							22
30–32		1	2	1	8	1	2	1							16
32–34			1		2	4	4	2		1	1			1	16
34–36						1				1		1	1	1	5
36–38								1							1
38–40															0
40–42															0
42–44															0
Total	12	43	26	13	19	7	6	5	0	2	1	1	1	2	138
Mean length [cm]	23	24	26	28	29	32	31	32		33	33	34	35	35	27

The (VBGF) which describes male, female and combined sex of blueline snapper at age can be expressed as:

$$\text{Male: TL [cm]} = 42\,[1 - e^{-0.21(t\,+\,0.22)}],\ (r^2 = 0.70)$$

$$\text{Female: TL [cm]} = 46\,[1 - e^{-0.16(t\,+\,0.15)}],\ (r^2 = 0.78)$$

$$\text{Combined sex: TL [cm]} = 44\,[1 - e^{-0.17(t\,+\,0.18)}]\ (r^2 = 0.73)$$

Table 2. Age–length key of *Lutjanus coeruleolineatus* females from Dhofar Governorate, Sultanate of Oman.

TL [cm]	Age [year]																		Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
18–20																			0
20–22	3	2																	5
22–24	3	17	1																21
24–26	3	15	6																24
26–28	1	5	12	4															22
28–30		6	2	13	2														23
30–32		2	3	8	5		1	1											20
32–34					5	3	2	1											11
34–36						3	2	1	2	1									9
36–38					1	2	2	1	3				1	2					12
38–40									2	1		1	1						5
40–42											1	1	1				1	1	5
42–44																	1		1
Total	10	47	24	25	13	8	7	4	7	2	1	2	3	2	0	0	2	1	158
Mean length [cm]	23	25	26	29	31	34	34	34	34	36	36	40	39	39			41	43	29

Table 3. Age–length key of sex combined *Lutjanus coeruleolineatus* from Dhofar Governorate, Sultanate of Oman.

TL [cm]	Age [year]																		Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
18–20																			0
20–22	4	7																	11
22–24	6	32	3																41
24–26	11	24	17		1														53
26–28	1	16	18	8	2														45
28–30		8	6	21	8	1		1											45
30–32		3	5	9	13	1	3	2											36
32–34			1		7	7	6	3		1	1			1					27
34–36					0	4	2	1	2	2		1	1	1					14
36–38					1	2	2	2	3				1	2					13
38–40									2	1		1	1						5
40–42											1	1	1				1	1	5
42–44																	1		1
Total	22	90	50	38	32	15	13	9	7	4	2	3	4	4	0	0	2	1	296
Mean length [cm]	23	24	26	28	30	33	32	33	36	35	36	36	38	36			41	43	28

MIR Ratios

Mean monthly marginal increment ratios (MIR ± SE) in the otoliths of blueline snapper are shown in Fig. 4. The MIR fluctuated during the year ranging between 0.48 and 0.79 mm and confirmed that the growth of translucent ring was slow. The MIR values showed a low mean value (0.56) between February and July and a high mean value (0.72) between August and December reaching a peak value (0.79) in November. These monthly changes in MIR over a year figured that the recognized otolith annulus was deposited once a year.

Mortality and exploitation rate

The coefficient of total mortality (Z) of blueline snapper was estimated by the length converted catch curve method (Z = 0.393) for combined sex (Fig. 5). The Z value estimated through the Beverton-Holt method revealed as Z = 0.350. Therefore, the mean value of Z value from two methods was taken and hence the Z = 0.372 was used for the calculation of fishing mortality. The natural mortality

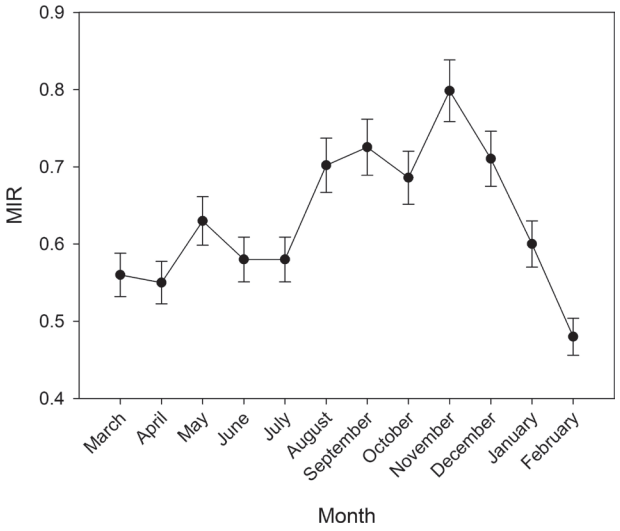

Figure 4. Monthly variations in the mean (±SE) marginal otolith increment (MIR) [mm] of blueline snappers *Lutjanus coeruleolineatus* in the Dhofar Governorate coast of the Arabian Sea from March 2015 to February 2016.

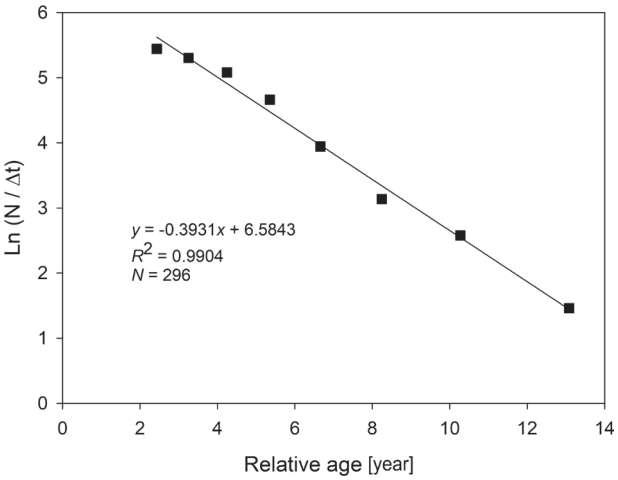

Figure 5. Length converted catch curve of blueline snapper, *Lutjanus coeruleolineatus*.

(*M*) calculated from the empirical equation using temperature and growth parameter (*K*), longevity, and growth parameter (*K*) was 0.47, 0.26, 0.24, 0.25, and 0.26 respectively. Thus, the mean values of natural mortality (*M*) from all methods were taken and equal to 0.296. Therefore, fishing mortality (*F*) was equal to 0.076 by subtracting the natural mortality (*M*) from the total mortality (*Z*). The exploitation rate (*E*) is estimated as 0.2.

Discussion

The basic biological studies such as morphometric, age and growth parameters, and reproductive characteristics are important in understanding the life history of the fishes. The maximum fish length of the presently reported species was 43.7 cm TL while previous estimation (Randall 1995) yielded 40 cm TL. We found a significant difference in the mean total length between males and females, with females having bigger body sizes than males. This observation coincides with other Lutjanidae fishes including *Lutjanus fulviflamma* (Forsskål, 1775) from southern Arabian Gulf (Grandcourt et al. 2006) and Mafia Island in Tanzania (Kamukuru et al. 2005), and *Lutjanus campechanus* (Poey, 1860) from the Atlantic waters of the southeastern USA (White and Palmer 2004). These results may be related to differences in metabolism between sexes, such as differences in the level of surplus energy between reproduction and somatic growth (Rljnsdorp and Ibelings 1989).

In the presently reported study, sectioned otoliths were used to estimate growth parameters. Various methods have been used for estimating growth parameters of *Lutjanus* species, but reading otolith sections are one of the best application for annuli determination due to its accuracy and reliability (Newman et al. 1996). Many previous listings suggested that snapper species generally have single annual ring formation (Cappo et al. 2000; Newman et al. 2000a, b; Burton 2002), corresponding to the majority of tropical fishes (e.g., Pilling et al. 2000). In addition, many previous studies have considered Lutjanidae fishes growing faster especially during their first year of their life history (Newman et al. 1996; Newman et al. 2000a; Kritzer 2004; Grandcourt et al. 2006).

Age–length frequency distributions for the presently reported blueline snapper revealed that only 1% of the samples were older than age 15. Although the sample size in this study was not enough for validating population-level age structure. Male's age ranged from 1 to 14 years, while females were between 1 and 18 years showing toward higher age distribution. The age structures were variable between sexes, with the female having the highest longevity at 18.7 years. This estimation of longevity is similar to those attained by *Lutjanus carponotatus* (Richardson, 1842) sampled within the Great Barrier Reef (Newman et al. 2000b; Kritzer 2004). On other hand, males blueline snapper had less life span (14.2 years) than females (18.7 years). Such results were also reported by Heupel et al. (2009) with male *Lutjanus gibbus* (Forsskål, 1775), *Aprion virescens* Valenciennes, 1830, and *Lutjanus fulviflamma* displaying shorter life spans of maximum ages of 12, 16, and 17 years, respectively. Shorter longevities in male snappers were also recorded in *Lutjanus vitta* (Quoy et Gaimard, 1824) (see Newman et al. 2000b), *Lutjanus guttatus* (Forsskål, 1775) (see Amezcua et al. 2006), and *L. fulviflamma* (see Grandcourt et al. 2006).

The asymptotic length (L_∞) of blueline snapper estimated was 44 cm TL for combined sex. The growth rate of males ($K = 0.21$) was higher than females ($K = 0.16$). Such finding is relatively in agreement with other Lutjanidae fishes (Newman et al. 2000b; Kamukuru et al. 2005; Heupel et al. 2010; Shimose and Nanami 2014). Additionally, Newman et al. (2000b) have clarified that the variations in the growth rate of *L. carponotatus* were probably linked to gonad maturation and sexual maturity. Moreover, the growth rate observed for blueline snapper was rapid during 3–4 years of age attaining over

25.0 cm TL for combined sexes and then became slower. Similar to this result, a growth study of blacktail snapper, *Lutjanus fulvus* (Forster, 1801), from the Yaeyama Islands, Okinawa, Japan revealed that such rapid growth is probably due to their maturation (Shimose and Nanami 2014). Shimose and Tachihara (2005) also suggested that reproductive status is often considered to be the main reason for inhibiting the growth of small *Lutjanus* species.

Some *Lutjanus* snappers have a relatively long life span and larger maximum size (≥50.0 cm TL), often exceed 40 years such as *Lutjanus bohar* (Forsskål, 1775) nearly close to 56 years (Marriott and Mapstone 2006), *L. campechanus* to 45 years (White and Palmer 2004), *Lutjanus malabaricus* (Bloch et Schneider, 1801) to 48 years, *Lutjanus erythropterus* Bloch, 1790 to 42 years (Fry et al. 2009), and *Lutjanus fulviflamma* (Forsskål, 1775) to 40 years (Shimose and Tachihara 2005). In contrast, some smaller *Lutjanus* snappers had a short life span; for example, the age of *Lutjanus ehrenbergii* (Peters, 1869) reaches to around 12 years (Grandcourt et al. 2011), *Lutjanus synagris* (Linnaeus, 1758) to 19 years (Luckhurst et al. 2000), *Lutjanus adetii* (Castelnau, 1873) to 12 years (Newman et al. 1996), and *Lutjanus sebae* (Cuvier, 1816) to 22 years (Newman et al. 2000a).

Estimates of natural mortality (M) for the presently reported species was 0.296 which is similar to those for other Lutjanidae fishes. Generally, many *Lutjanus* species are long-lived fishes and have a low value of the instantaneous rate of natural mortality; for instance, natural mortality of *Lutjanus analis* ranged from 0.28 and 0.49 (Burton 2002) and *L. campechanus* was 0.11 (Topping and Szedlmayer 2013). Newman et al. (2000b) also investigated the life histories of two species (*L. carponotatus* and *L. vitta*) and found the natural mortalities of those species were between 0.20–0.21 and between 0.34–0.35, respectively. Moreover, the natural mortality of *L. griseus* was between 0.15 and 0.50 (Fischer et al. 2005), *L. fulviflamma* was around 0.29 (Grandcourt et al. 2006) and *L. carponotatus* was between 0.18 and 0.30 (Heupel et al. 2010). While, Pauly (1980) estimated the natural mortality of fishes via Von Bertalanffy growth parameters (L_∞ or W_∞, and K) and mean environmental temperature (T), and assumed that there is a relation between fish size and natural mortality. Environmental factors such as seawater temperature possibly affect animal life; e.g., warm water will have higher mortality rates than an equivalent animal living in cooler water (Pauly 1980). Whereas estimation of natural mortality for the presently reported species that lives in warm waters have a similar range of that species that inhabiting colder waters.

The presently reported study estimation of the annual instantaneous rate of mortality (Z) for the blueline snapper in the Dhofar Governorate was 0.372 and the fishing mortality (F) was 0.076. Total mortality calculations based on the length converted catch curve method has been recorded high value (0.393) than the Beverton–Holt method (0.350). Estimates were greatly lower than that found by Burton (2002) ($Z = 0.49$) and higher than Mason and Manooch (1985) ($Z = 0.33$) for *L. analis*. The optimum exploitation rate (E) is assumed to be close to 0.5 (Gulland 1971). We compared the exploitation status of blueline snapper (presently-reported study) with results from previous studies on different families for demersal fish in Oman. The exploitation rate (E) of blueline snapper was 0.2 showing the stock at a lower optimum level of exploitation. Similar to these results, Al-Mamry et al. (2011) stated that the exploitation status of sea bream species, *Argyrops spinifer* (Forsskål, 1775) was optimal and the stock was in a healthy status. On the contrary, Abd El Barr (2016) specified that overexploitation of emperors, groupers, sea bream, and rabbit fish due to the rise number of boats and increase fishing activities on those species. Few studies on exploitation status of demersal fish caught from the artisanal fishery in Oman. Therefore, further studies are required to compare the exploitation status between demersal species.

The study was competent to investigate age structure, growth rate, and the mortality of blueline snapper, *L. coeruleolineatus* in Omani waters (Arabian Sea). The length and weight distributions between females and males were comparable to those reported in *L. fulviflamma* from Southern Arabian Gulf, Mafia Island in Tanzania, and *Lutjanus campechanus* from the northern Gulf of Mexico suggesting females having bigger and heavier body than males (Wilson and Nieland 2001; Kamukuru and Mgaya 2004). Estimation of growth rate was rapid during the first 3–4 years of age attaining over 25.0 cm TL and then became slower. This study provides basic biological data that is useful in sustainable fishery management of this species in the Sultanate of Oman.

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