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Original Article

Length-based fishery status and population dynamics of Spiral Babylon, *Babylonia spirata*, Linnaeus, 1758, stock in the northern waters of the Oman Sea, Sistan and Baluchestan Province of Iran

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Abstract: In the present study, the population characteristics of Spiral Babylon, *Babylonia spirata*, were evaluated by sampling at four sites in the northern Oman Sea, Iran, including Pozm, Konark, Beries, Pasabandar from March 2021 to March 2022. A total of 2779 Babylonian snail specimens (1489 males, and 1290 females) were measured and about ten percent of the specimens were described. The mean length and weight of males and females were 36±5, and 32±5 mm and 14±6, 10±4 g, respectively. Growth and mortality indices for females and males including infinite length ($L\infty$ = 68 and 76 mm), growth coefficient (K = 0.54 and 0.3 (yr^{-1})), natural mortality (M= 0.7 and 0.4 (yr^{-1})), fishing mortality (F = 2.30 and 1.79 (yr^{-1})), total mortality (Z = 3 and 2.19 (yr^{-1})) and exploitation coefficient (E = 0.77 and 0.82 (yr^{-1})) were estimated. Based on the LBSPR assessment model, estimated to be about 0.3, and a ratio of P_{mega}<0.1, L_{mean}/L_{opt} <1 and L_{mean} /$L_{F=M}$<1 show considered undesirable. The present study showed that the Spiral Babylon stock has reached 'overfished' status.

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Introduction

Population dynamics are driven by changes in the abundance or biomass of a population through time by a series of life-history traits such as fecundity, successful recruitment, growth rates, and mortality rates. Estimates of population dynamics can provide insights into a harvested marine population species. It can indicate how a population arrived at its current state and how it might change in the future (Brown and Guy, 2007). Recruitment, growth, and mortality rates are the primary population dynamics parameters that explained the harvestable part of a fish population (Brown and Guy, 2007).

Mollusca is the second phylum in the number of living species, after arthropods (Pandian, 2017). Of the seven molluscan classes, the 78,000 known gastropod species contribute 85% of all mollusks and the 60,000 species of prosobranchs contribute a significant part of this group (Pandian, 2017). The genus Babylonia (Mollusca: Gastropoda: Buccinidae) possesses 11 extant species, two of which polytypic with two subspecies each, and 12 fossil and extinct species (Gittenberger, and Goud, 2014*).* The three most common species, viz. *Babylonia areolata*, *B. japonica* and *B. spirata,* have continuous ranges (Gittenberger and Goud, 2014).

The Oman Sea is a region of the northern Indian Ocean that connects the Arabian Sea with the Strait of Hormuz, which then runs to the Persian Gulf. It borders Iran and Pakistan on the north, Oman on the south, and the United Arab Emirates on the west (Taghavimotlagh and Shojaei, 2017). The Oman Sea, with its unique ecological conditions, hosts a wide variety of marine species that provide livelihood, employment, and vast economic activities for the settlers. Iran has more than 120,000 fishermen. Therefore, fishing has played a major role in creating employment in coastal areas, as well as in

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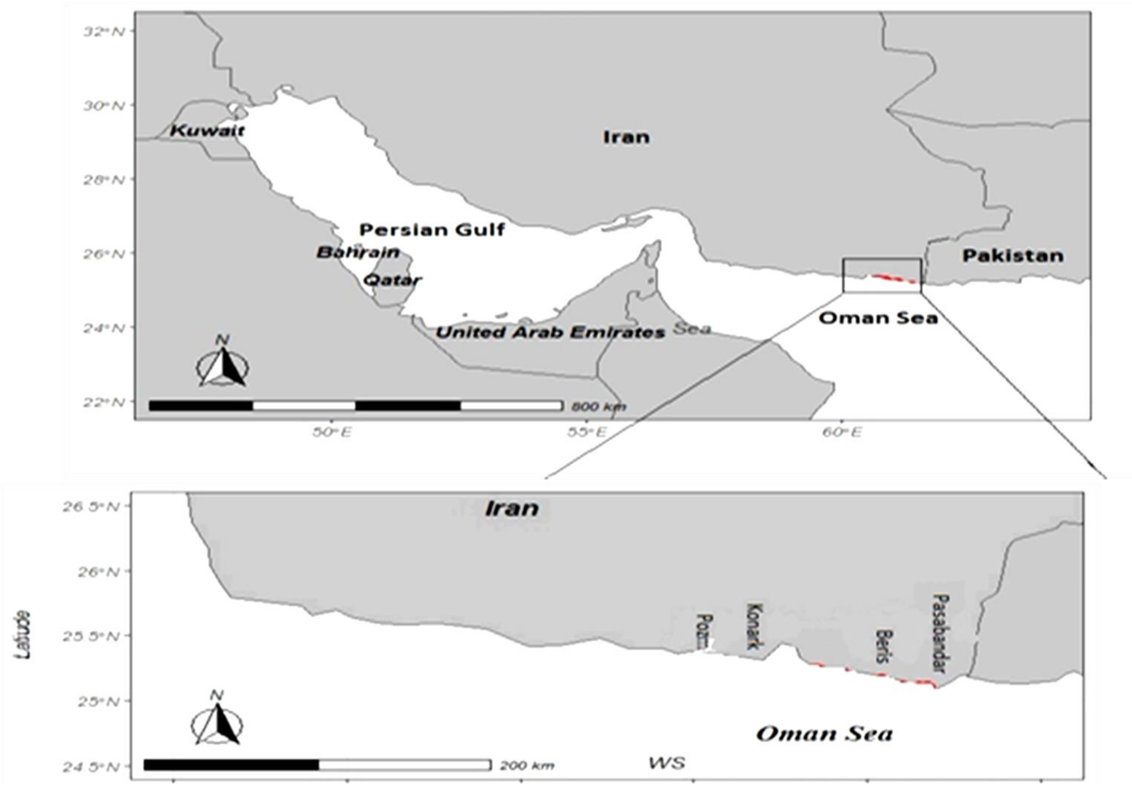

Figure 1. Map of *Babylonia spirata* sampling stations in the northern Oman Sea, Iran.

economic activities for post-harvest operations (Taghavimotlagh and Shojaei, 2017).

Some studies on the biological characteristics of shell species in different parts of the world include Mohan (2007), Cob et al. (2009), Arrighetti et al. (2012), Daza-Guerra et al. (2018), and Matos et al. (2020). Recently, the illegal fishing of *Babylonia spirata* in the northern waters of the Oman Sea has increased significantly. It is not used for food in the region and is caught only for export. There is currently no specific management or restriction for this species in this area. Despite the economic importance of this species, little is known about the stock of *B. spirata* population. Therefore, this study investigates several life-history traits and fish assessment measures of *B. spirata* from the Oman Sea to provide fundamental information for proper identification and management. Hence, first, the structure of the population and growth rate of *B. spirata* from the Oman Sea will be studied; then, a series of fisheries assessment data will be calculated such as mortality and exploitation coefficient to evaluate the sustainability of its population in the Oman Sea.

Materials and methods

Sample sites and specimen collection: Based on the location in the northern Oman Sea, Iran, four sites were selected for sampling *B. spirata* in the ports of Pozem (60˚15´E, 25˚35´N), Konark (60˚28´E, 25˚60´N), Beris (61˚10´E, 25˚82´N) and Pasabandar (61˚25´E, 25˚70´N) (Fig. 1). Samplings were carried out monthly from March 2017 to March 2022. Samples were collected with the help of fishermen using special baskets from subtidal areas (sandy and pebble shore) at depths of less than 50 meters. A total of 2779 specimens of *B. spirata* specimens were collected (Fig. 2).

Biometric data: The shell weight and length of all specimens were measured. The total length was determined by a biometric ruler with 1 mm precision (Fig. 2) and wet weight to the nearest 1 gr. The Equation of $Wi = a \times Li^{b}$ (1) was used to calculate the relationship between the total length and wet weight, where, Wi is the shell weight (g), Li is the shell length (mm), a is a constant coefficient, and b,

Figure 2. The *Babylonia spirata* species in the northern Oman Sea, Iran.

an equation power. Equation (2) was used to decipher significant differences between the calculated b from Equation (1) and $b = 3$ for a shell of similar growth with *s.dx*, the standard deviation of total length natural log, *s. dy* standard deviation of weight natural log,b slope, r^2 coefficient of determination, and n is sample sizes (Zar, 2010).

$$t = [(s.dx)/ (s.dy)] \times [(lb\text{-}3l)/ (\sqrt{(l\text{-}r^2)}] \times [\sqrt{(n\text{-}2)}] \quad (2)$$

Population dynamic parameters of *B. spirata*: The data were pooled monthly from different stations, and subsequently grouped into classes of three centimeters interval. The ELEFAN method was used to analyze the data for growth rates. The estimation of $L\infty$, the infinite length was obtained using Equation (3) and the maximum length of samples (L_{max}) based on Froese and Binohlan (2000)

$$\text{Log } L\infty = 0.044 + 0.9841 * \text{Log } (L_{max}) \quad (3)$$

The growth rate was obtained by applying the ELEFAN method (optimization model), using the RStudio software with the TropFishR package (Mildenberger et al., 2017). The optimum value of t_0 (time that length is zero) was calculated by the experimental formula of Pauly equation (Equation (4)) with K, the growth factor (Froese and Binohlan, 2000).

$$\text{Log } (-t_0) = - 0.3922 - 0.2752 \text{ Log } L\infty - 1.038 \text{ Log } K \quad (4)$$

The maximum lifespan was estimated based on Froese and Pauly (2017 and the equation of $t_{max} = t_0 + 3 / K$ (5).

Mortality: Natural mortality (M) was calculated based on the Brey Equation (6) with, M as the annual natural mortality coefficient, A_{max} as the life expectancy based on the year, BM_{max} as the maximum body weight (30*3.81) based on K J (for this species the coefficient is 3.81 kJ /g) and T (Kelvin) is the average ambient temperature (*Brey, 1999; Mohan*, 2007).

$$\log (M) = 1.672 +(0.993* \log (1/A_{max}))) - (0.035* \log (BM_{max})) - (300.447/ T+273) \quad (6)$$

The mean annual temperature of the sea surface of the northern Oman Sea was estimated at 26°C or 299 (K) (Hashemi, 2020). Total mortality (Z) was calculated based on the length-converted catch curves data. The fishing mortality was estimated using Equation (7), with Z, the total mortality, F, the fishing mortality, and M the natural mortality.

$$F = Z - M \quad (7)$$

The exploitation rate (E), which is the ratio of fishing mortality to total mortality, was calculated using Equation (8) based on Sparre and Venema (1998)

$$E = F / Z \quad (8)$$

The relative yield per recruitment (Y/R) and relative biomass per recruitment (B'/R): The relative yield per recruitment (Y/R) was estimated against the fishing mortality coefficient or exploitation rate. In this Equation (9), E is the exploitation coefficient, U is the exploitation rate, M is the natural mortality coefficient, F is the fishing mortality coefficient and L_c (Length at first capture) is the same as Lc_{50} (Gayanilo et al., 2003).

$$Y' / R = EU^{M/K} (-3 U / (1 + m) + 3 U^2 / (1 + 2m) + U^3 / (1 + 3m) \text{ with}$$

$$U = 1 - (L_C / L_\infty) \; ; \; m = (1 - E) / (M / K) = (K / Z) \; ; \; E = F / Z \quad (9)$$

In addition, the relative biomass per recruitment (B'/R) was calculated using the Equation of B' / R= Y' / R / *F* (10).

Length-based indicators (LBI): In the length-based indicators (LBI), P_{opt} is the percentage of fish caught at the optimum length for harvest, P_{mega}, is the percentage of mega-spawners (length between 1.1 L_{opt} and L_{max} on the catch length composition) in the catch, and $L_{F=M}$ is values for optimal fishing length that were calculated using the formula of 11, 12, and 13, respectively (Froese and Binohlan, 2000; Cousido-Rocha et al., 2022*):*

$$L_{opt}=L_{inf} (3/(3+M/K)) \quad (11)$$

$$L_{F=M} = (0.75L_c+0.25L_{inf}) \quad (12)$$

$$P_{mega}= L_{opt} + \%10 \quad (13)$$

Length-based spawning potential ratio (LBSPR): LBSPR is one of the biological reference points for determining the stock status of a species in the population. The reference points of LBSPR used are: LBSPR 20% is as the limit reference point and LBSPR 40% is a target reference point (Hordyk et al., 2015) that is calculated as:

$$\text{LBSPR} = \frac{\sum(1-LX)^{(M/K)[(F/M)+1])L_x^b}}{\sum(1-L_X)^{\;M/K}\, L_x^b} \quad (14)$$

Where Lx is fork length, M is natural mortality; k is the growth rate, F is fishing mortality, and b is exponent usually close to 3. Estimating SPR with those functions needs the simple assumptions of asymptotic or logistic selectivity and no variation in length at age. The F/M ratio can be estimated from the length composition of the catch (Hordyk et al., 2015). The relationship between F/M and SPR is asymptotic and determined by the selectivity parameters (Carruthers and Hordyk, 2018).

Statistical analyses: Comparison of population dynamic values between male and female lengths, and weights were tested by Student's Test (*t*-test) with paired *t*-test and independent *t*-test, respectively. The normality of this data was assessed using the Kolmogorov–Smirnov test. Data analyses were performed using FiSAT II and R Studio softwares (1.1.46) with the TropFishR package.

Results

Length frequency distribution: The mean ± standard deviation of total length (Lm) and total weight (Wm) for male (1489 specimens) and female (1290 specimens) were 36±6 (18-58 mm), and 32±5 (19-50mm), and 14±6 (12-63 g), 10±5 (21-50 g), respectively. The differences between total length and total weight in both sexes were not significant ($t = 1.45$, $P= 0.05$; $t = 1.44$, $P>0.05$, respectively). The length (TL) data were categorized into 3-mm groups which the highest frequency belonging to individuals with 27 to 30 mm (Fig. 3A).

Length-weight relationship: The relationship between length and weight give a=0.0008 and b= 2.66 (R^2 = 0.89) for female, and for male, a=0.008 and b=2.71 (R^2 = 0.88) and for both sexes a=0.0008 and b=2.70 (R^2 = 0.88). The results showed significant differences between estimated b and b=3 at the level of 0.05 (Fig. 3B), which means a negative allometric growth pattern for both sexes of *B. spirata* in the northern waters of the Oman Sea.

Growth studies: The population dynamic parameters of male, female, and both sex of *B. spirata* are detailed in Table 1. Growth parameters for both sexes together were $L\infty$ = 71 mm ($W\infty$ = 79 gr), K = 0.35 (yr^{-1}), and t_0= -0.2.

The growth curve (Fig. 4) highlighted 6 cohorts and age groups and the growth performance index as Φ = 3.11. There is recruitment throughout the year and the highest rate of recruitment is observed in the winter and summer season's time. Based on the results, the maximum lifespan of this species was nearly 8 years.

Mortality estimate (M): The natural mortality (M), fishing mortality (F), and total mortality (Z) were estimated as 0.5 (yr^{-1}), 1.75 (yr^{-1}), and 2.25 (yr^{-1}), respectively (Table 1). The exploitation coefficient was estimated as 0.78 (yr^{-1}) (Fig. 5). Based on the calculated parameters, the von Bertalanffy equations for this species (length and weight) in the northern Oman Sea, Iran, are as follows.

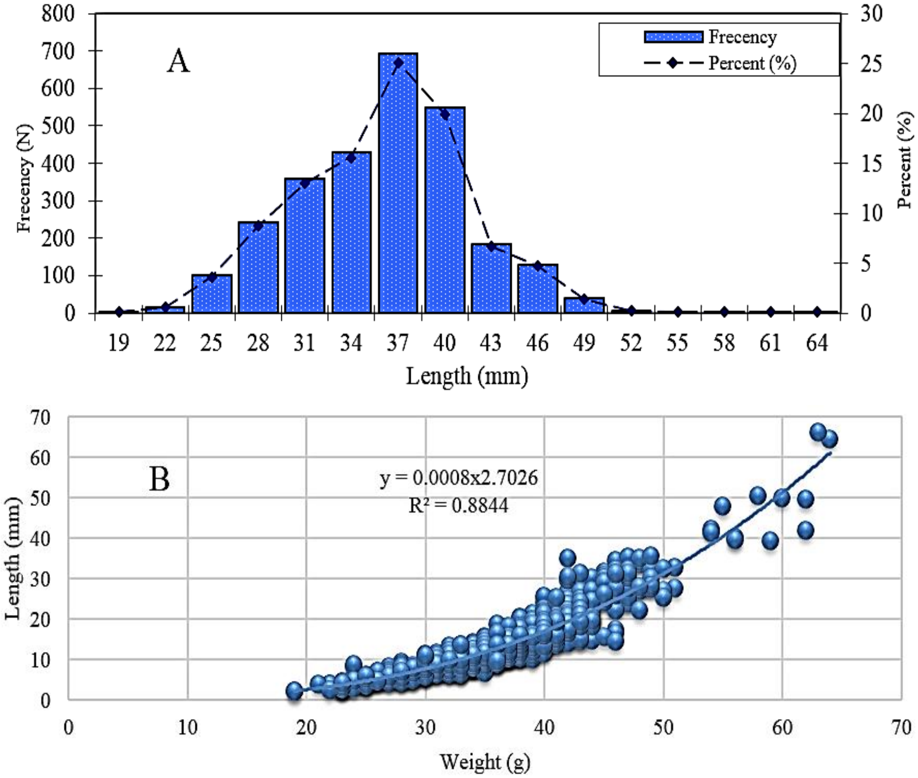

Figure 3. Length and Frequency (A) as well as Length - weight relationship (B) of total *Babylonia spirata* in the northern Oman Sea, Iran.

Table 1. Comparison of population dynamics values of *Babylonia spirata* with two methods (Shepherd method and ELEFAN method) ($L\infty$= infinite length, K= Growth rate, t_o= time that length is zero, M= Natural mortality, F= Fishing mortality, Z= Total mortality, E= Exploitation rate).

Species (sex)	Method	$L\infty$ (mm)	(yr^{-1}K)	t_o	M	F	Z	E
B. spirata (Male)	*ELEFAN*	76	0.3	-0.42	0.4	1.79	2.19	0.82
B. spirata (Female)	*ELEFAN*	68	0.54	-0.24	0.7	2.3	3	0.77
B. spirata (Total)	*ELEFAN*	71	0.35	-0.37	0.5	1.75	2.25	0.78

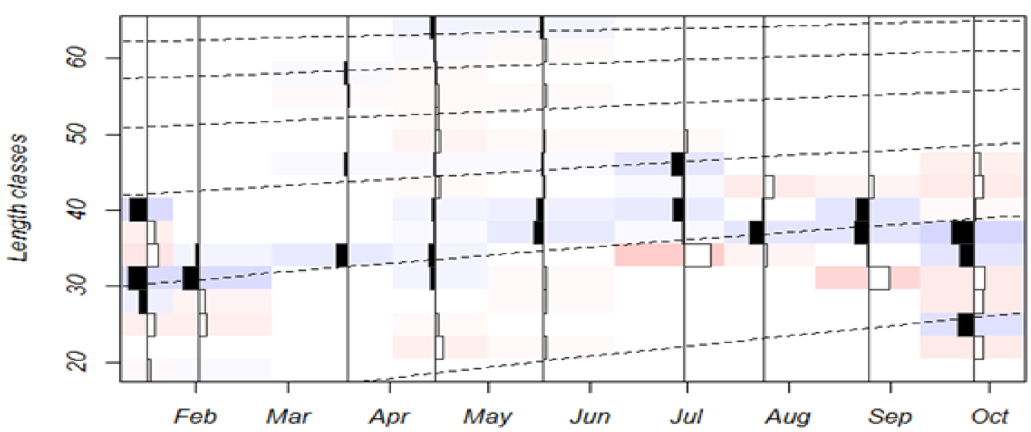

Figure 4. Growth curve derived from the structure of population of *Babylonia spirata* from the northern Oman Sea (Iran). The growth curve plot shows reconstructed frequencies, with negative and positive values as white and black colored histograms, respectively. The background shading shows runs of peaks, with positive peaks in blue, negative peaks in red, and values of zero in white. The different color backgrounds were added in order to help visualizing sign and magnitude of the bin values. The sum of all positive peaks is called the "available sum of peaks" (ASP), which represents a maximum possible score. The "estimated sum of peaks" (ESP) is the sum of peak values crossed by the growth curves.

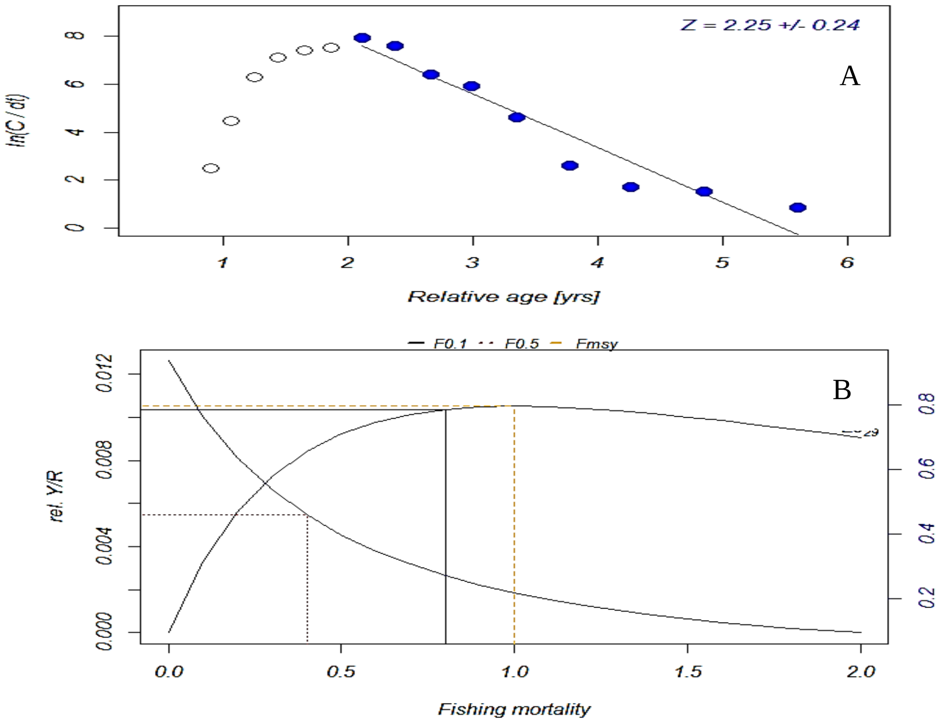

Figure 5. Exploitation coefficient curve (A) and Relative Yield per Recruit (*Y'/R)* and Relative Biomass per Recruit *(*B'/R), F_{MSY} (B) of *Babylonia spirata* (total) in the northern Oman Sea, Iran (F_{MSY} = Fishing mortality rate of Maximum sustainable yield, $F_{0.5}$= fishing mortality rate at which the slope of the yield-per-recruit curve is only half the slope of the curve at its origin, $F_{0.1}$= fishing mortality rate at which the slope of the yield-per-recruit curve is only one percent the slope of the curve at its origin).

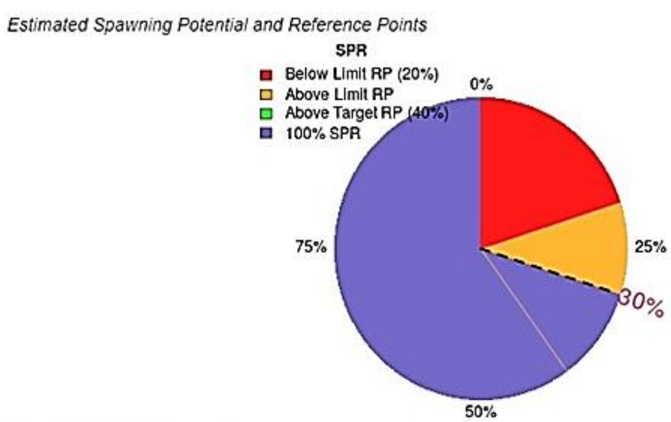

Figure 6. The LBSPR of *Babylonia spirata (*total) in the northern Oman Sea, Iran.

$$L_t = 71\ (1 - \exp\ (-0.35\ (t + 0.2)))$$

$$W_t = 79\ (1 - \exp\ (-0.35\ (t + 0.2)))\ ^\wedge\ {}^{2.70}$$

The relative yield per recruitment (Y/R) and relative biomass per recruitment (B'/R): Based on length at first capture (*Lc* = 29 mm), which is 50% the probability of catching shell, relative production per recruitment and relative biomass per recruitment were estimated as *Y'/R* = 0.009 and *B'/R* = 0.2, respectively. The results demonstrate an exploitation rate (*U*) of 0.70 and the fishing mortality at maximum sustainable yield (F_{msy}) equaled to 1 for this stock (Fig. 5).

Length-based indicators (LBI) and length-based spawning potential ratio (LBSPR): Length-based reference point is the percentage of shell caught at the optimum length for harvest (L_{opt}=48 mm, P_{opt}=0.10), ($L_{F=M}$=40 mm, P_{opt}=0.13) and percentage of mega-spawners in the catch (L_{mega}=53 mm, P_{mega}=0.04), respectively. Based on the LBSPR assessment model (Fig. 6), L_{opt} was estimated at about 0.3 (0.27-0.33). The ratio of P_{mega}<0.1, L_{mean}/ L_{opt} <1 and L_{mean} /$L_{F=M}$ <1 were estimated.

Table 2. Comparison of population dynamic values of *Babylonia spirata* with other studies around the world. For details of the abbreviation name of the values see Table 1.

References	Species/Region	L∞ (mm)	K (yr^{-1})	M	F	Z	E
Mohan (2007)	*B. spirata*, India	68	1.08	1.61	4.44	6.05	0.73
Mohan (2007)	*B. zeylanica*, India	76	1.15	1.65	3.37	5.02	0.67
Cob et al. (2009)	*Strombus canarium*, Malaysia	70 (F) 69 (M)	1.5 (F) 1.2 (M)	0.95 (F) 0.86 (M	1.61 (F) 1.86 (M)	2.56 (F) 2.86 (M)	0.62 (F) 0.65 (M
Arrighetti et al. (2012)	*Olivancillaria deshayesiana*, Argentina	38	0.14	0.36	0.29	0.65	0.44
Daza-Guerra et al. (2018)	*Cittarium pica*, Colombia	94	0.32	0.60	1.11	1.71	0.65
Present study (2022)	*B. spirata*, Oman Sea (Iran)	71	0.35	0.5	1.75	2.25	0.78

Discussion

We have managed to study a series of population dynamics values of the species *B. spirata* and this is the first time in the study area despite economic and ecological importance. *Babylonia spirata* is one of the economically valuable species in the southern and northern Oman Sea, Iran.

Life-history traits of *B. spirata*: The L-W relationship showed negative allometric growth and the female was heavier than males in the same length group. It seems the growth curve (length and weight) of *B. spirata* (total) slows down after two years and allometric growth is common in Gasterpoda (Carare and Surugiu, 2020). The relationship between the length and weight of *Strombus canarium* was calculated as a = 0.0000018 and b = 3.2 (R^2 = 0.85) for males, and for females, a = 0.0000015 and b = 3.3 (R^2 = 0.81) (Cob et al., 2009). The observed size pattern was influenced by latitude and local spatial responses to factors such as the substrate changing the morphometric variables of the snail. The morphological characteristics such as length and weight relationship, are greatly affected by latitude, and it seems that as the latitude increases, the size of the snail becomes larger (Matos et al., 2020). In addition, the morphological characteristics of snails are influenced by various factors such as temperature, available food, intra-group competition, substrate, climate, tidal conditions, and specific characteristics of habitat (Matos et al., 2020).

The L-W relationship is of great importance in fishery assessments (Haimovic and Velasco, 2000). According to Marthin (1994), the range of "*b*" could be from 2.5 to 4 and it is believed *b* = 3 with isometric growth. Also, the functional regression *b*-value shows the body form, and it is directly related to the weight affected by ecological factors such as temperature, food supply, spawning conditions, and also other factors, such as sex, age, fishing time, and area and fishing vessels.

Population dynamic of *B. spirata*: Comparisons of the population parameters of *B. spirata* with other studies in different parts of the world (Table 2) show that the infinite length and growth coefficient of males from different species are smaller than females. Also, the infinite length and growth coefficient of different species changes in various regions (Table 2). Differences in the range of the infinite length and growth rate are influenced by the ecological differences of each region (King, 2007). The growth rate is expected to be higher in the tropical zones. Higher K-values for species are common in tropical waters due to their poikilothermic nature and result in a higher metabolic rate in relation to high temperate (Hashemi, 2020). In general, the difference in the infinite length and growth rate in various regions might be due to the quantity and quality of food and climatic conditions (Bartulovic et al., 2004). Various factors can also affect holothurian growth including age, sex, season, year, type of feeding, physiological conditions, differences in food availability, and reproductive period (Lalèyè, 2006).

The natural mortality rate of *B. spirata* in this study was less than that of fishing mortality. The ratio of fishing mortality to maximum sustainable yield (F/F_{MSY}) was over than one. To recall that if the value of F/F_{MSY} is more than 1, it indicates that there is overfishing (Arrizabalaga et al., 2012). The exploitation coefficient was over 0.5, indicating that the amount of capture fisheries was more than the optimum level. The exploitation coefficient should not be greater than 0.5 or, the fishing mortality should not exceed natural mortality otherwise they indicate overfishing (King, 2007; Hashemi et al., 2021; Hashemi and Doustdar, 2022). The most important factors affecting the pressure on stocks are, first, the amount of catch and harvest of the stocks, and second, the environmental factors that affect survival and access to the fishery resources (Mateus and Estupinan, 2002).

Length-based indicators (LBI) and length-based spawning potential ratio (LBSPR): The L_{mean}/L_{opt} index has values less than one (about 0.7), which means the presence of overfishing, and also $L_{mean}/L_{F=M}$ index has values less than one (about 0.8) and P_{mega} less than 0.1 is calculated which the show considered undesirable and index range optimal of L_{mean}/L_{opt} and $L_{mean}/L_{F=M}$ is close to one and P_{mega} is about 0.3-0.4 (Cousido-Rocha et al., 2022).

The LBSPR rate of this species was calculated at 0.3 (30%). LBSPR gives estimates of spawning potential ratio (SPR), where values below 0.2 (≈ 0.5 B/Bmsy) indicate depletion and values above 0.4 (≈ 1.0 B/Bmsy) indicate good stock status. The 95% confidence limits provided by LBSPR are unrealistically narrow, sometimes close to deterministic, which partly explains their very low matching score. In conclusion, the LBSPR model is a promising tool for the length-based assessment of data-limited fish stocks (Hordyk et al., 2015). With regards to cheap and simple to collect measurements of the length composition of an exploited stock and also life-history information, models, and methods have been developed in recent years, for instance, the length-based spawning potential ratio method (LBSPR) (Hordyk et al., 2015).

Management and conservation of *B. spirata* in the Oman Sea: It is recommended that appropriate instructions be established for the harvesting and management of this species in the area. This parameter is needed for fisheries management and conservation of exploited this species. The present study showed that these stocks have reached 'overfished' status. The results of the present study could help in the management and sustainable exploitation of this species' stocks.

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