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Original Article

Life-history and population dynamic of the White treads fish, *Holothuria leucospilota* in the Iranian part of the Oman Sea with a note on its conservation and management

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Abstract: In the present study, the Life-history and population dynamic characteristics of *Holothuria leucospilota* were evaluated in the Iranian part of the Oman Sea by sampling at nine sites, including Ramin, Kachoo, Aliabady, Beries, Beries plane, Pasabandar, Tis, Pozm and Gurdium from March 2017 to March 2018. Biometric data of 862 specimens were obtained, and the growth and mortality indices, including infinite length ($L\infty$ = 50.5 cm), growth coefficient (K = 0.51 (yr^{-1})), growth performance index (Φ = 3.11), natural mortality (M = 0.94(yr^{-1})), fishing mortality (F = 0.56 (yr^{-1})), total mortality (Z = 1.50±0.12 (yr^{-1})) and exploitation coefficient (E = 0.36 (yr^{-1})) and time zero (-0.27) were calculated. Mean of relative production per recruitment (Y' / R_p), relative biomass per recruitment (B' / R_p) and exploitation rate (U) of the studied population of *H. leucospilota* were 0.02, 0.30, and 0.28, respectively. Mean GSI and maturity stage indicated that the spawning seasons were June (spring) and December (autumn). The mean size at first sexual maturity (LM_{50}) was 246 mm for males, 220 mm for females and 225 mm for both sexes. The results of the current work showed that the studied *H. leucospilota* stock had not yet reached to overfished' status.

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Introduction

Sea cucumbers conservation and management are necessary because these marine benthic species have an important ecological role, such as the recycling of nutrients (Shiell and Knott, 2010), and are a significant source of income for many coastal communities worldwide (Purcell, 2010). The current status of sea cucumber stocks in many countries shows poor fishery management, and international efforts are made on their culture in different countries to minimize the depletion of their natural population. The unique life-history traits of holothurians e.g. low or infrequent recruitment and density-dependent reproductive success, make these species vulnerable to overfishing (Purcell, 2010).

Population dynamics are driven by changes in abundance or biomass of a population through time by a series of life-history traits such as fecundity, successful recruitment, growth, and mortality. Estimates of population dynamics can provide great insight 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 explain the harvestable part of a fish population (Brown and Guy, 2007).

Holothuria leucospilota (Brandt, 1835) (Dendrochirotida; Holothuriidae) is harvested commercially. This species lives in shallow habitats up to 10 m, mainly on outer and inner reef flats, back reefs, seagrass beds, microatoll detrital fringe, and shallow coastal lagoons but with higher densities on the inner reef slopes. It is common, with its distribution extending into warm-temperate zones. *Holothuria leucospilota* is a deposit feeder with an

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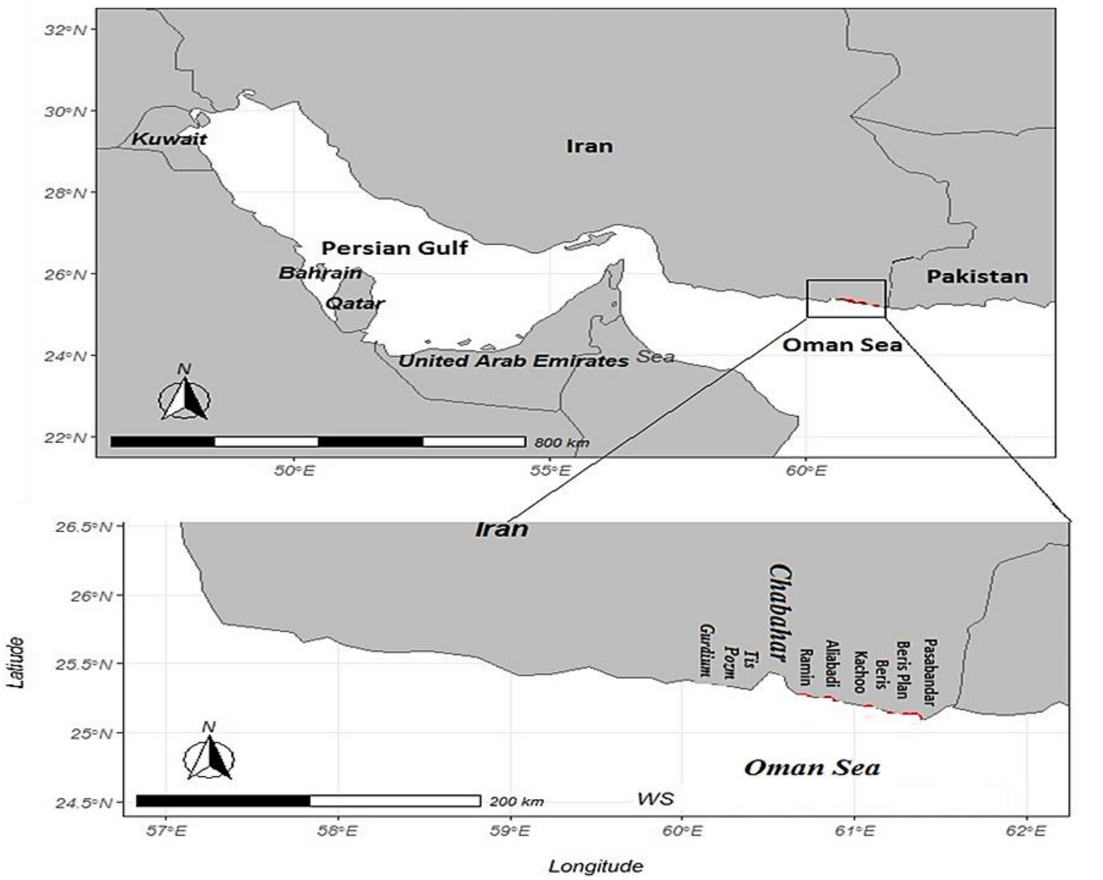


Figure 1. Map of *Holothuria leucospilota* sampling stations in the northern Oman sea, Iran.

important ecological role (Purcell et al., 2012). Studies on the biological characteristics of sea cucumber species in different parts of the world are done (Herrero-Perezrul et al., 1999; Skewes et al., 2002; Uthicke et al., 2004; Conand, 2008; Choo, 2008; Purcell et al., 2009; Dissanayake and Stefansson, 2010; Chávez et al., 2011; de Jesús-Navarrete et al., 2018).

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). With its unique ecological conditions, the Oman Sea 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 significantly created employment in coastal areas and economic activities for post-harvest operations (Taghavimotlagh and Shojaei, 2017).

Recently, the illegal fishing of *H. leucospilota* in the northern waters of the Oman Sea has increased significantly, and they are caught 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 its stock population. Hence, this study aimed to investigate some life-history traits and assessment measures of *H. leucospilota* from the Oman Sea to provide basic information. First, the structure of the population, spawning period, gonadosomatic index, size at first maturity, and growth rate of *H. leucospilota* will be studied. Then, a series of fisheries assessment data, such as biomass, recruitment, and mortality, will be calculated to evaluate its population sustainability in the northern part of the Oman Sea.

Materials and Methods

Nine sampling sites, including the ports of Ramin

Table 1. Comparison of population dynamics values of *Holothuria leucospilota* with two methods (Shepherd and ELEFAN) (L∞ = infinite length, K = Growth rate, to = time that length is zero, Φ' = Growth performance index, M = Natural mortality, F = Fishing mortality, Z = Total mortality, and E = Exploitation rate).

species (sex)	Method	L∞ (cm)	K (yr $^{-1}$)	t_o	Φ'	M	F	Z	E
H. leucospilota (Male)	Shepherd method (FiSAT II)	49	0.6	-0.28	3.09	0.95	0.64	1.59	0.4
H. leucospilota (Female)	Shepherd method (FiSAT II)	47	0.45	-0.28	3.09	0.95	0.64	1.59	0.4
H. leucospilota (Total)	Shepherd method (FiSAT II)	49	0.5	-0.28	3.09	0.95	0.64	1.59	0.4
H. leucospilota (Male)	ELEFAN method (R)	56	0.54	-0.26	3.13	1	0.4	1.4	0.29
H. leucospilota (Female)	ELEFAN method (R)	50	0.44	-0.31	3.15	0.84	0.71	1.55	0.46
H. leucospilota (Total)	ELEFAN method (R)	52	0.54	-0.25	3.14	0.95	0.35	1.3	0.26
(Total) *H. leucospilota*	Mean of Both	50.5±3	0.51±0.06	0.27±0.02	3.11±0.02	0.94±0.05	0.56±0.14	1.5±0.12	0.36±0.07

(60°45´E, 25°15´N), Kachoo (60°55´E, 25°16´N), Aliabady (61°05´E, 25°10´N), Beris (61°10´E, 25°82´ N), Beris plane (61°15´E, 25°72´N), Pasabandar (61° 25´E, 25°70´N), Tis (60°35´E, 25°24´N), Pozm (60° 16´E, 25°23´N) and Gurdim (59°61´E, 25°22´N) (Fig. 1) were selected for sampling in the Iranian part of northern Oman sea. Samplings were done monthly from March 2017 to March 2018. Samples were collected with the help of divers from subtidal areas of sandy and pebbles shore at depths of less than 10 meters. Additionally, they were captured using a linear transect 50 meters long and 2.0 meters wide using scuba diving. A total of 802 specimens of *H. leucospilota* were collected (Table 1).

The weight and length of the specimens were measured after placing them in a potassium chloride solution (10%) for half an hour. Biometric measurements, including length and weight, were performed on sea cucumber after anesthesia. Total length was measured using a biometric ruler with 1 mm precision (Fig. 2) and wet weight by the nearest 1 g.

The equation of $Wi = a \times Li^{b}$ was used to calculate the relationship between the total length and wet weight, where Wi is the sea cucumber weight (g), Li is the sea cucumber length (mm), a is a constant coefficient, and b is an equation power. The equation of $t = [(s.dx)/ (s.dy)] \times [(lb\text{-}3l)/ (\sqrt{} (1\text{-}r^2)] \times [\sqrt{} (n\text{-}2)]$ was used to decipher significant differences between the calculated b. In this equation b = 3 for a sea cucumber of similar growth with $s.dx$ = standard deviation of total length natural log, $s.dy$ = standard deviation of weight natural log, b = slope, r^2 = coefficient of determination and n = sample sizes (Zar, 2010).

Life-history traits and population dynamic parameters

Structure of population and growth rates: The data was pooled monthly from different stations and subsequently grouped into classes with 3 cm intervals. Two methods were used to analyze the data for growth rates viz. (1) Shepherd, and (2) ELEFAN (Electronic Length Frequency Analysis). In method 1, the data was analyzed using FiSAT II (FAO-ICLARM Stock Assessment Tools, www.fao.org/fi) based on the Shepherd method (Gayanilo et al., 2003). In method 2, the estimation of L∞, the infinite length was obtained using the equation of Log Loo = 0.044 + 0.9841 * Log (Lmax) and Maximum length of samples (Lmax) based on Froese and Binohlan (2000).

The growth rate was obtained by applying the ELEFAN (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 Pauly equation of Log $(-t_0)$ = - 0.3922 - 0.2752 Log L∞ - 1.038 Log K, where K is the growth factor (Froese and Binohlan, 2000). A comparison of growth indices such as infinite length

Figure 2. *Holothuria leucospilota* from the northern Oman Sea, Iran.

($L\infty$) and growth factor (K) was performed using the equation of $\Phi' = \text{Log}(K) + 2\,\text{Log}(L\infty)$. In addition, the maximum lifespan of this species was calculated based on the formula of $t_{max} = t_0 + 3 / K$ (Froese and Pauly, 2017).

Mortality: Natural mortality (*M*) was calculated based on the Pauly equation of $\text{Ln}(M) = -0.0152 - 0.297\,\text{Ln}(L\infty) + 0.654\,\text{Ln}(K) + 0.642\,\text{Ln}(T)$, where, *M* is the annual natural mortality coefficient, $L\infty$ is the infinite length of the sea cucumber (cm), *K* is the growth curve parameter of von Bertalanffy growth equation and T (Celsius) is the mean environmental temperature (Sparre and Venema, 1998).

The mean annual temperature of the northern Oman Sea surface was estimated as 26°C (Keymaram et al., 2009). Total mortality (*Z*) was calculated using the length-converted catch curves data. The fishing mortality was estimated using the eq $F = Z - M$ equation, where Z = the total mortality, F= the fishing mortality, and *M* the natural mortality. The exploitation rate (*E*), which is the ratio of fishing mortality to total mortality, was calculated using the equation of $E = F / Z$ (Sparre and Venema, 1998).

Recruitment and biomass: The relative yield per recruitment (Y/R) was estimated against the fishing mortality coefficient or exploitation rate. In the equation of $Y'/R = EU^{M/K}(-3Um/(1+m) + 3U^2/(1+2m) + U^3/(1+3m)$ with $U = 1 - (L_C / L_\infty)$; $m = (1-E)/(M/K) = (K/Z)$; $E = F/Z$, *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 L_{c50} (Gayanilo et al., 2003). In addition, the relative biomass per recruitment (B' / R) was calculated using the equation of $B'/R = Y'/R/F$.

The gonadosomatic index (GSI)*:* The maturity stage for males and females (Fig. 6) were determined macroscopically using a 5-stage maturity key (*Gaudron et al., 2008*), including (1) *resting* (I), *immature* stage (II), *growing* stage (III), *maturation* stage (IV), and *post-spawning* stage (V). The GSI was calculated by expressing the mean gonad weight as a proportion of the total body weight (Biswas, 1993). The GI was calculated using the equation, GI = GW / EV, where GI is gonad index (%), GW is gonad weight and EW is eviscerated body weight (Gaudron

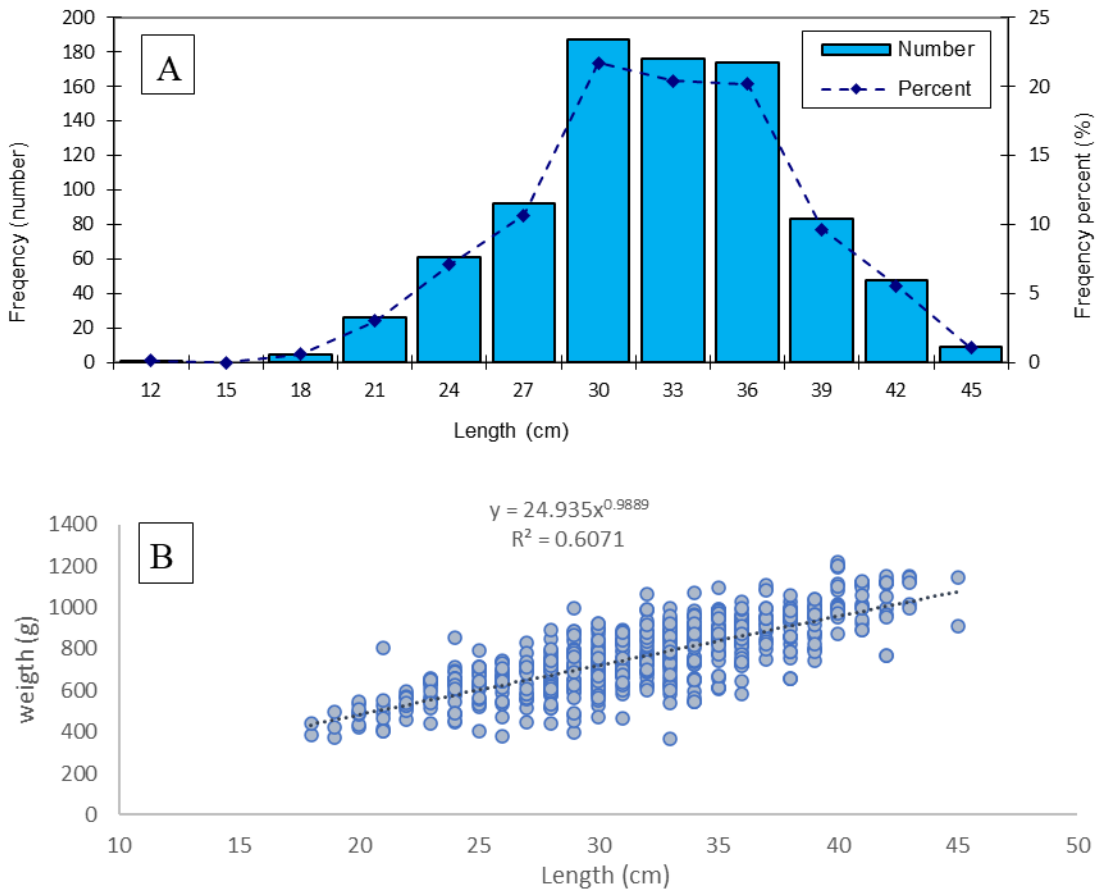


Figure 3. Length and frequency (A) and length-weight relationship (B) of total *Holothuria leucospilota* in the northern Oman Sea, Iran.

et al., 2008).

The mean size at first sexual maturity (LM_{50}): The mean size at first sexual maturity (LM_{50}) was estimated for females by fitting the logistic function to the proportion of mature sea cucumbers in 4 cm (TL) size categories $Y = 1 / 1 + \exp(-a\text{-}bX)$, where Y is the proportion of the number of all mature males and females to all immature males and females in the same length class, X is the total length in cm and a and b are correlation constants (King, 2007). The mean size at first maturity was taken when 50% of individuals were mature. Monthly sea temperature data (°C) were recorded in different stations (by multi-parameter device, Hach model).

Statistical analyses: Comparison of population dynamic values in two methods (*Shepherd and* ELEFAN methods) and between male and female lengths and weights were tested using Student's Test (*t*-test) with paired *t*-test and independent *t*-test, respectively. The correlation between temperature and GSI was tested by a Pearson correlation test. A chi-square test was used to assess the sex ratio difference between males and females. The normality of data was assessed by using the Kolmogorov–Smirnov test. Data analyses were performed using FiSAT II and R Studio (1.1.46) with the TropFishR package.

Results

Length frequency distribution: The mean ± standard deviation of total length and total weight for male (624 specimens) and female (178 specimens) were 31±6 (18-45) and 31±5 (19-43) cm, and, 770±164 (370-1220) and 762±155 (375-1125) g, respectively. The differences between total length and total weight in both sexes were not significant (t = 0.83, P>0.05; t = 0.58, P>0.05, respectively). The length (TL) data were categorized into 3-cm groups, which the highest frequency (195 sea cucumber), were belonging to individuals with 27 to 30 cm length (Fig. 3A).

Length-weight relationship (LWR)**:** In LWR, the

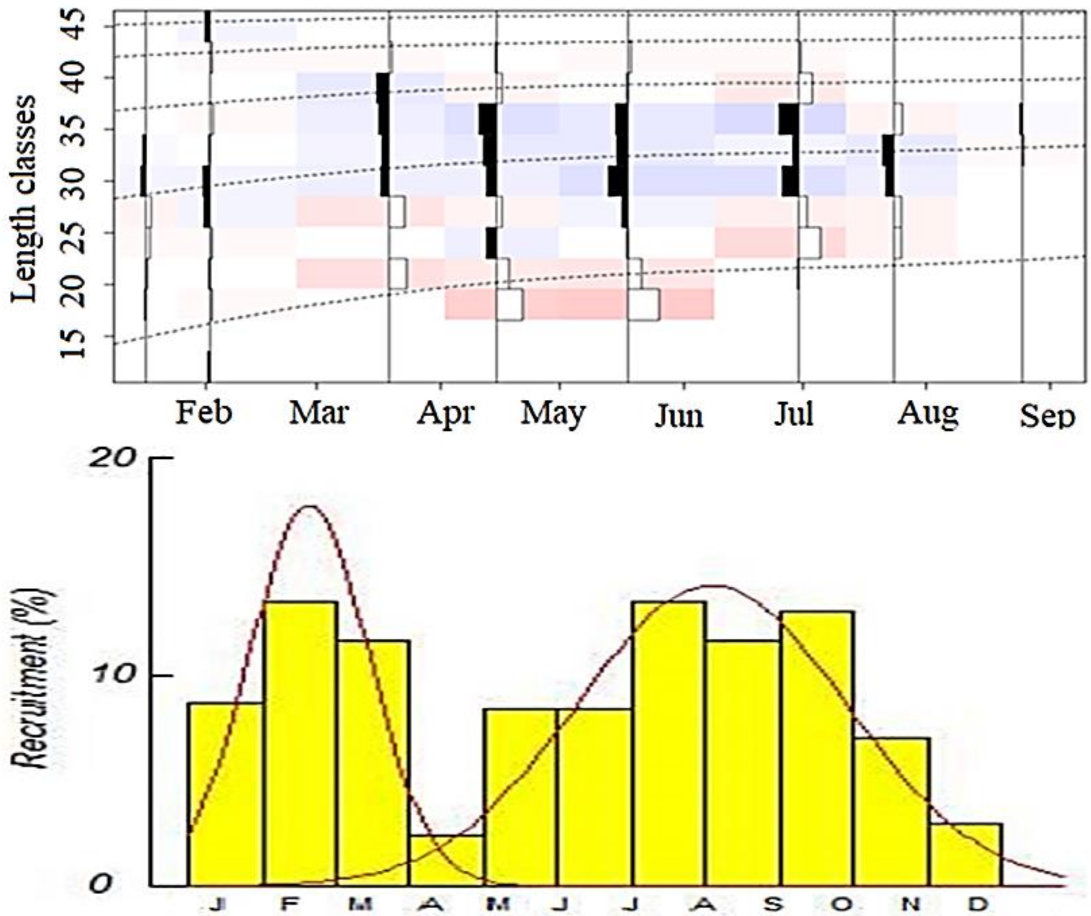


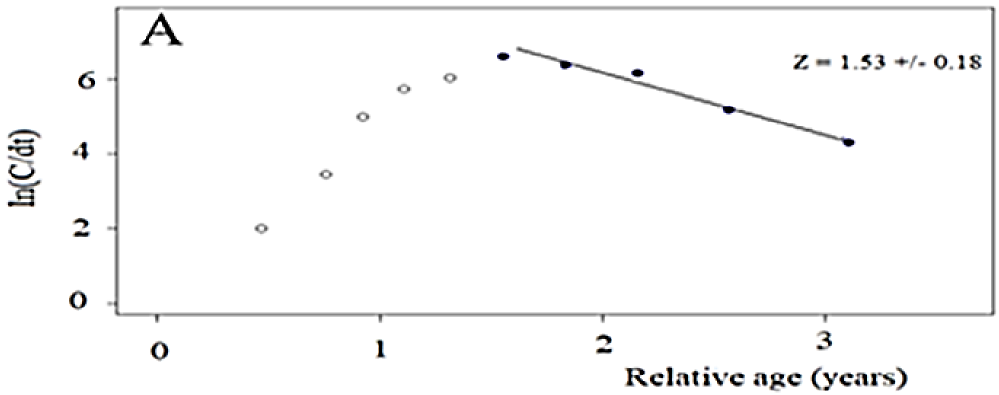
Figure 4. Growth curve (A) and monthly recruitment in percent (B) derived from the structure of the population of *Holothuria leucospilota* from the northern Oman sea (Iran). (A) The growth curve plot shows reconstructed frequencies, with negative and positive values as white and black colored histograms, 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 colour backgrounds were added in order to help visualize the 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 (Pauly, 1985).

parameters were $a = 25.76$ and $b = 0.97$ ($R^2 = 0.61$) for female, $a = 30.79$ and $b = 0.92$ ($R^2 = 0.93$) for male, and $a = 24.93$ and $b = 0.98$ ($R^2 = 0.59$) for both sexes. The results showed significant differences between estimated b from 3 ($P<0.05$) (Fig. 3B), which means an allometric growth pattern for both sexes.

Growth parameters: The population dynamic parameters using the two methods of Shepherd and ELEFAN for male, female, and both sexes are presented in Table 1. There were no significant differences between the two methods ($P>0.05$). Growth parameters for both sexes were estimated as $L\infty = 50.5$ cm ($W\infty = 1.211$ kg), $K = 0.51$ (yr^{-1}), and $t_0 = -0.27$. The growth curve (Fig. 4A). Highlighted six cohorts and age groups and the growth performance index was estimated as $\Phi = 3.11$. There is recruitment throughout the year and the highest recruitment rate was observed in the winter and summer seasons (Fig. 4B). Based on the results, the maximum lifespan of this species was near 6 years.

Mortality estimate: The natural mortality (M), fishing mortality (F) and total mortality (Z) were estimated 0.94 (yr^{-1}), 0.56 (yr^{-1}), and 1.5 (yr^{-1}), respectively. The exploitation coefficient was estimated as 0.36 (yr^{-1}) (Fig. 5). Based on the results, the von Bertalanffy equation for this species in the northern Oman sea of Iran was $L_t = 50.5\ (1 - \exp(-0.51\ (t + 0.27)))$ and $W_t = 1211\ (1 - \exp(-0.51\ (t + 0.27)))\ ^\wedge\ ^{0.98}$.

Yield per recruit and biomass per recruit: Based on



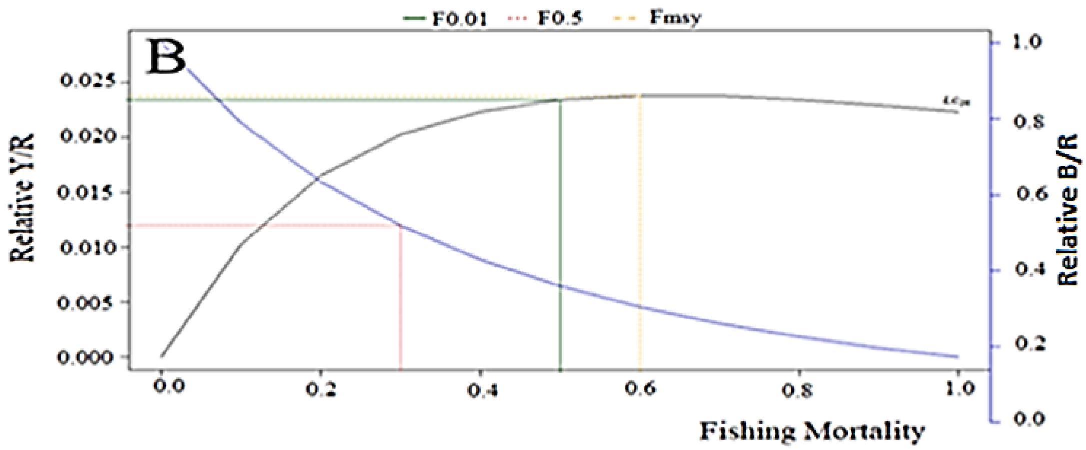


Figure 5. Exploitation coefficient curve (A, method 2) and Relative Yield per Recruit (Y' / R) and Relative Biomass per Recruit (B' / R), F_{MSY} (B) of *Holothuria leucospilota* (total) in the northern Oman sea (Iran) (F_{MSY} = Fishing mortality rate of Maximum sustainable yield, $F_{0.5}$= fishing mortality rate at which the slope of the yield-per-recruit curve is only half the slope of the curve at its origin, $F_{0.01}$= 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).

length at first capture (Lc = 27 cm), which is 50% the probability of catching sea cucumber, the relative production per recruitment and relative biomass per recruitment were estimated $Y' / R_p = 0.02$ and $B' / R_p = 0.3$, respectively. The results showed an exploitation rate (U) of 0.28 and fishing mortality at a maximum sustainable yield ($Fmsy$) of 0.6 (Fig. 5).

Sex ratio, GSI, and LM_{50}: From all sea cucumbers sampled, 639 were male (75%) and only 223 were female (25%). The sex ratio was significantly biased towards males (1 female/ 3 males) ($Chi^2 = 100.38$, $P<0.05$). The mean value of GSI for both sexes was 5.59±1.75. The highest GSI value was observed in June (21±6) and December (8±2), and the lowest value in August (1±0.5) (Fig. 6). Moreover, there was no significant correlation between the GSI temporal evolution and the monthly temperature (Pearson correlation = 0.30, $P>0.05$). Mean GSI and maturity stage indicated that spawning occurred in June (spring) and December (autumn). The mean size at first sexual maturity (LM_{50}) was 246 mm for males, 220 mm for females, and 225 mm for both sexes (Fig. 7).

Discussions

For the first time, we investigated some life-history traits and population dynamics of *H. leucospilota* in the study area. This species is economically valuable in the south and northern Oman sea, Iran. The sea cucumbers play a 'key role in the structure of marine ecosystems mainly in organic matter processing. Overfishing sea cucumbers on a tropical scale is likely to affect their structure in ecosystems (Uthicke et al., 2009).

Life-history traits: The LWR of *H. leucospilota* in the current study showed an allometric growth pattern

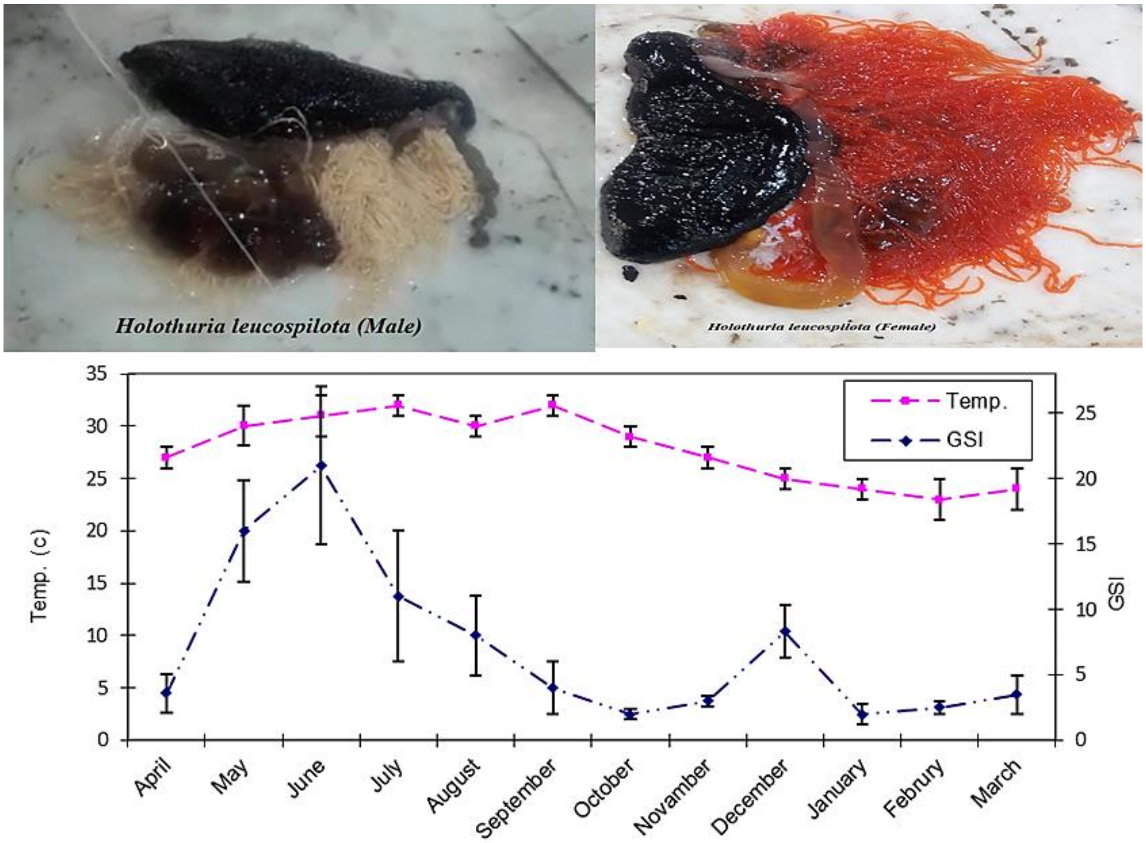


Figure 6. Monthly variation of GSI (male and female) of *Holothuria leucospilota* (total) and temperature in the northern Oman Sea, Iran.

and the female was heavier than males in the same length group. The growth curve (length and weight) of *H. leucospilota* slows down after two years and an allometric growth pattern is common in sea cucumbers (Al-Rashdi et al., 2007; Herrero-Perezrul et al., 1999; Chávez et al., 2011; Dereli et al., 2016). The relationship between length and weight for *H. tubulosa* had reported $W = 7.66\ L^{1.06}$ ($R^2 = 0.52$) (Dereli et al., 2016), for *Parastichopus parvimensis* $W = 0.4\ L^{1.83}$ (Chávez et al., 2011), for *H. scabra* $W = 0.0033\ L^{2.17}$ ($R^2 = 0.80$) (Al-Rashdi et al., 2007), and for *Isostichopus fuscus* $W = 1.14\ L^{1.83}$ (Herrero-Perezrul et al., 1999). According to Marthin (1994) the range of "b" could be 2.5 to 4. The b-value shows the body form and is directly related to the weight affected by ecological factors such as temperature, food supply, spawning conditions, and other factors, such as sex, age, fishing time, and area and fishing vessels (Ricker, 1973).

In the present study, *H. leucospilota* was shown to spawn twice a year, with a major peak in June and a weaker one in December that was not correlated with temperature. The percentage of recruitment also emphasizes spawning in the winter and summer seasons. Spawning time of *H. leucospilota* was reported from November to April in Australia (Franklin, 1980), November to March in the Cook Islands (Drumm and Loneragan, 2005), June-September in Taiwan (Choo, 2008), February and May in the Indian Ocean (Conand, 2008), February and May in the Western Indian (Gaudron et al., 2008), and from June to October in Daya Bay, China (Huang et al., 2018). The difference in the spawning period of any species is affected by regional conditions, and in tropical areas, almost shallow-water holothurians have an annual 2- to 3-month spawning period. Most of the tropical shallow-water holothurians spawn during the warm months. The holothurians have different reproductive patterns and need to be studied in each region (Chao, 1995). The sea cucumber reproduction cycle differs among species and even within a species distributed in different regions (Huang et al., 2018).

The size at first sexual maturity (LM_{50}) for White threads fish was estimated at 246 mm for males and

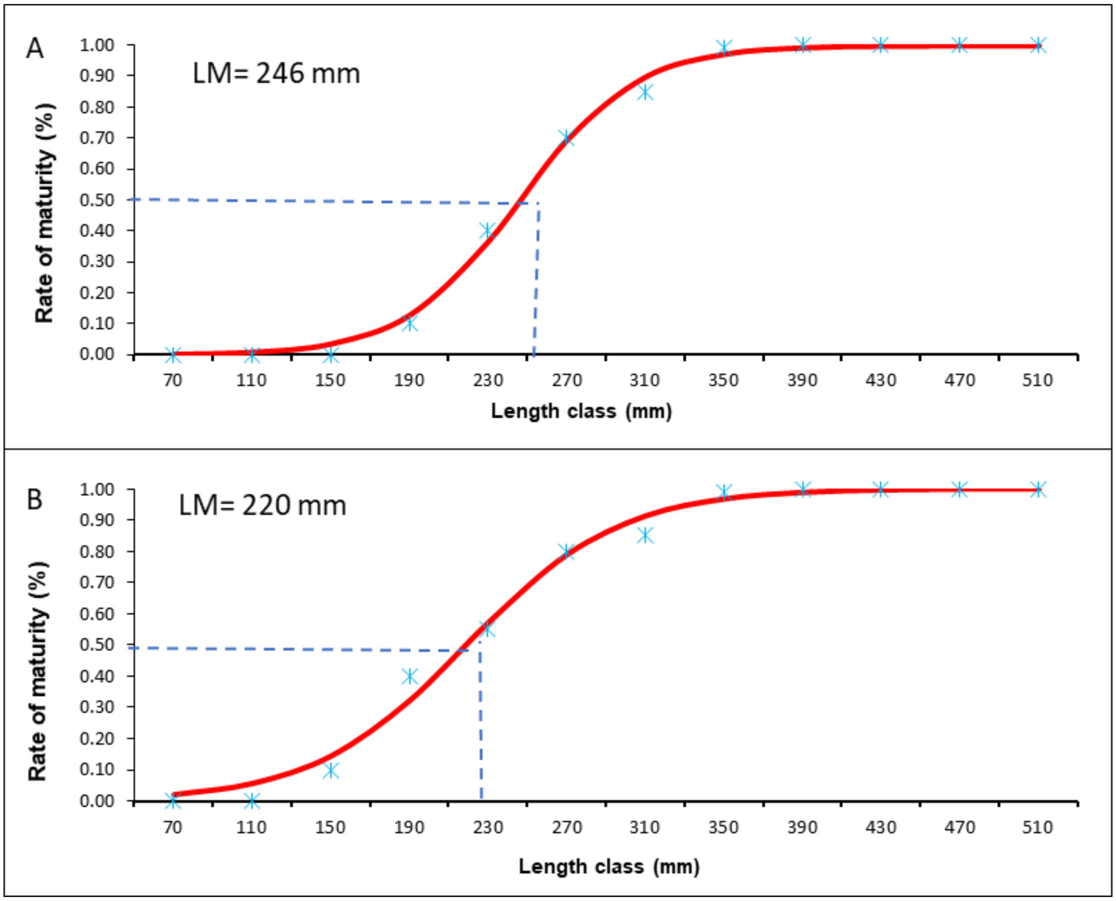


Figure 7. The LM50 (Male (A)) and (Female (B)) of *Holohturia leucospilota* (total) and Temperature in the northern Oman Sea, Iran.

220 mm for females. Females mature earlier, therefore, their growth is slower than males, resulting from the high energy they need in earlier years for their growth and reproduction. Therefore, females *H. leucospilota* have a L∞ value smaller than males. The size at first maturity (LM_{50}) of *H. sanctori* was reported as 201 to 210 mm in the eastern Atlantic, Spain (Conand, 1993) and *H. atra* as 165 mm (males), 155 mm (females) in Egypt (Abdel Razek et al., 2005). The size at first maturity is an important parameter for managing the stock, as it helps to limit capture sizes (Conand, 2008) and tools for enhancing sustainable management of the fisheries (Kohler et al., 2009). This parameter is needed for fisheries management, conservation of exploited sea cucumbers, and small immature individuals' collection decreases for the sustainability of the population.

Population dynamic: Comparisons of the population dynamic parameters of *H. leucospilota* with other studies in different parts of the world are presented in Table 2. As seen in Table 2, the L∞ and growth coefficient of females in different species are smaller than those of males. In addition, these characters in different species differ in various regions (Table 2). Differences in the L∞ 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 resulting in higher metabolic rates in high temperate (Hashemi et al., 2015). The differences in the L∞ and growth rate 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 mean growth performance index (Φ') was 3.11 in the current study. There is a correlation

Table 2. Comparison of population dynamic values of *Holothuria leucospilota* with other studies around the world. For abbreviations see Table 1.

References	Species / Region	L∞ (cm)	K (yr^{-1})	t_0	Φ'	M	F	Z	E
Herrero-Perezrul et al. (1999)	*Isostichopus fuscus* Galapagos Islands	36.11	0.18	-	-	0.51	-	-	-
Chávez et al. (2011)	*Parastichopus parvimensis* California, USA	50	0.6	0.10	3.2	0.85	-	-	-
De Jesús-Navarrete et al. (2018)	*Isostichopus badionotus* Yucatan, Mexico	40.3	0.25	0.18	-	0.38	0.5	0.88	0.54
Present study	*H. leucospilota* Oman Sea, Iran	50.5	50.1	0.27	3.11	0.94	0.56	1.50	0.36

between L∞, and growth rate. The growth curve has a rate with constant changes at different times and sizes. Differences in ecological conditions and latitude changes can affect the values of inf L∞ and growth rate (King, 2007). This study's natural mortality rate of *H. leucospilota* was higher than fishing mortality. The ratio of fishing mortality to maximum sustainable yield (F / F_{MSY}) was less than one. The F / F_{MSY} of more than 1 indicates overfishing (Arrizabalaga et al., 2012). However, our work's exploitation coefficient was less than 0.5, indicating that the fisheries were not more than the optimum level. The exploitation coefficient and exploitation rate should not exceed 0.5, and the fishing mortality should not exceed natural mortality otherwise, they indicate overfishing (Sparre and Venema, 1998; King, 2007). The most important factors affecting the pressure on stocks are the amount of catch and the environmental factors that affect survival and access to the fishery resources (Mateus and Estupinan, 2002).

Management and conservation: It is recommended that appropriate instructions be established for the harvesting and management of *H. leucospilota* in the northern Oman Sea. This species should not harvest in lengths less than 250 mm and in winter and summer because of its spawning season. The size at first maturity is an important parameter for managing this stock, as it helps to limit capture sizes (Conand, 2008). This parameter is needed for fisheries management, conservation of exploited sea cucumbers, and avoiding small immature individuals' collection its sustainability of the population. The present work revealed that the studied stocks had not yet reached 'overfished' status.

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