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1 **Life-history traits and population dynamic of the white threadfish, *Holothuria***
2 ***leucospilota* in the Iranian part of the Oman Sea with a note on its conservation and**
3 **management**

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24 **Abstract**

25 Population characteristics of *Holothuria leucospilota* were evaluated by sampling at nine sites
26 in the northern Oman Sea (Iran) from March 2017 to March 2018. Mean of growth and
27 mortality indices were calculated including infinite length ($L_{\infty} = 50.5$ cm), growth coefficient
28 ($K = 0.51$ (yr⁻¹)), growth performance index ($\Phi = 3.11$), natural mortality ($M = 0.94$ yr⁻¹),
29 fishing mortality ($F = 0.56$ yr⁻¹), total mortality ($Z = 1.50 \pm 0.12$ yr⁻¹) and exploitation
30 coefficient ($E = 0.36$ yr⁻¹). Mean of relative production and relative biomass per recruitment,
31 and exploitation rate of this species were $Y/R_p = 0.02$, $B/R_p = 0.30$ and $U = 0.28$,
32 respectively. Mean gonado-somatic index indicated that spawning time occurred during June
33 and December. The mean size at first sexual maturity (LM_{50}) was 246 mm for males, 220 mm
34 for females and 225 mm for both sexes. The lifespan was estimated at 6 years. The present
35 study has demonstrated that the white threads fish stock in the northern Oman Sea has not
36 reached yet the 'overfished' status but as illegal fishing occurs within the studied area, this
37 does not exclude a specific management or restriction of the fishing of this species for its
38 conservation.

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41 **Keywords:** stock assessment, conservation, sea cucumber, reproduction, exploitation
42 coefficient, growth rate, mortality indices, lifespan and recruitment.

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52 **1. Introduction**

53 Sea cucumbers conservation and management are necessary because these marine benthic
54 species have an important ecological role in the marine ecosystems such as the recycling of
55 nutrients (Shiell & Knott, 2010) but in the meantime are a significant source of income for
56 many coastal communities worldwide (Purcell, 2010). From both an ecological and socio-
57 economic perspectives, the long-term sustainability of sea cucumber fisheries is of great
58 importance to coastal communities. The current status of sea cucumber stocks in numerous
59 countries has poor fishery management due to prevalent exploitation and ever-increasing
60 market demand. However, there is an international effort on aquaculture in different countries
61 to minimize the depletion of natural population. The unique life-history traits of holothurians
62 (e.g. low or infrequent recruitment and density-dependent reproductive success) also make
63 these species especially vulnerable to overfishing (Purcell, 2010). Population dynamics are
64 driven by changes in abundance or biomass of a population through time by a series of life-
65 history traits such as fecundity, successful recruitment, growth rates and mortality rates.
66 Estimation of population dynamics can provide greater insight into a harvested marine
67 population species. It can indicate how a population arrives at its current state and how it may
68 change in the future (Brown & Guy, 2007). Recruitment, growth, and mortality rates are the
69 primary population dynamics parameters that explain the harvestable part of a fish population
70 (Brown & Guy, 2007).

71 *Holothuria leucospilota* (Brandt, 1835) belongs to the phylum of Echinodermata and is fished
72 commercially. Sea cucumbers belong to the class Holothuroidea and are referred to as
73 holothurians ('bêche-de-mer', 'trepan' or 'hai-som'). The dominant species harvested
74 commercially belong to the order Aspidochirotida, with the two families Holothuriidae and
75 Stichopodidae that are dominantly found in tropical zones (Purcell, Samyn & Conand, 2012).
76 *H. leucospilota* lives in shallow habitats up to 10 m depth, mostly on outer and inner reef flats,
77 back reefs, seagrass beds, microatoll detrital fringe, shallow coastal lagoons but with higher
78 densities on the inner reef slopes. This species is very common, with its distribution extending
79 into warm-temperate zones. It is a deposit-feeder and therefore has an important ecological
80 role (Purcell, Samyn & Conand, 2012).

81 The Oman Sea is a region of the northern Indian Ocean that connects the Arabian Sea with the
82 Strait of Hormuz, which then runs to the Persian Gulf. It borders Iran and Pakistan on the
83 north, Oman on the south, and the United Arab Emirates on the west (Taghavimotlagh &
84 Shojaei, 2017). The Oman Sea, with its unique ecological conditions, hosts a wide variety of
85 marine species that provide livelihood, employment and vast economic activities for the

86 settlers. Iran has more than 120,000 fishermen. Therefore fishing has played a major role in
87 creating employment in coastal areas, as well as in economic activities for post-harvested
88 operations (Taghavimotlagh & Shojaei, 2017). A numerous studies on biological and
89 ecological characteristics (reproduction, growth, population dynamics, fishing pressure, etc.)
90 of several harvested sea cucumber species were carried out in different parts of the world
91 (Herrero-Perezrul et al., 1999; Skewes et al., 2002; Uthicke, Welch & Benzie, 2004; Conand,
92 2008; Choo, 2008; Purcell, Gossuin & Agudo, 2009; Dissanayake & Stefansson, 2010;
93 Chávez, De Lourdes-Salgado & Palleiro, 2011; De Jesús-Navarrete, Poot & Medina-Quej,
94 2018).

95 Recently, the illegal fishing of *H. leucospilota* in the northern waters of the Oman Sea has
96 increased significantly. It is not used for local consumption in the region but it is caught for
97 exportation. There is currently no specific management or restriction for this species in this
98 area. Despite the ecological and economical importance of this species, little is known about
99 the stock of *H. leucospilota* population. This study investigates several life-history traits and
100 stock assessment measures of *H. leucospilota* from Oman Sea in order to provide fundamental
101 information for identifying and managing properly this species. First, structure of population,
102 lifespan, spawning period, gonado-somatic index, size at first maturity and growth rate of *H.*
103 *leucospilota* from the Oman Sea will be presented. Then, a series of fisheries assessment data
104 will be estimated such as biomass, recruitment and mortality in order to evaluate the
105 sustainability of the *H. leucospilota* population in the Oman Sea.

106

107 **2. Methods**

108 **2.1 Sample sites and specimen collection**

109 Based on the location in the northern Oman sea (Iran), nine sites were selected for sampling
110 *Holothuria leucospilota* in the ports of Ramin (60° 45'E, 25° 15'N), Kachoo (60° 55'E, 25°
111 16'N), Aliabady (61° 05'E, 25° 10'N), Beris (61° 10'E, 25° 82'N), Beris plane (61° 15'E, 25°
112 72'N), Pasabandar (61° 25'E, 25° 70'N) Tis (60° 35'E, 25° 24'N), Pozm (60° 16'E, 25° 23'N)
113 and Gurdim (59° 61'E, 25° 22'N) (Fig. 1). Samplings were carried out monthly in the nine
114 sites from March 2017 to March 2018. Sea cucumbers were collected with the help of divers
115 in subtidal areas (sandy and Pebbles shore) at depths of less than 10 meters. Additionally, in
116 the fishing area, organisms were captured using a linear transect 50 meters long and 2 meters

117 wide, using scuba diving. A total of 802 specimens of *H. leucospilota* species were collected.
118 The weight and length of all specimens were measured. The collected organisms were placed
119 in a potassium chloride solution (10%) for half an hour prior to biometric measurements.

120

121 **2.2 Biometry**

122 Biometric measurements (length and weight) were performed on anesthetized sea cucumbers.
123 Total length (TL) was determined by a biometric ruler with 1 mm precision (Fig. 2) and wet
124 weight with a scale to the nearest 1 gr.

125 The Equation (1) was used to calculate the relationship between the total length and wet
126 weight, with, W_i the sea cucumber weight (g), L_i , the sea cucumber length (mm), a , a constant
127 coefficient, and b , an equation power

$$128 \quad W_i = a \times L_i^b \quad (1)$$

129

130 The Equation (2) was used to decipher significant differences between the calculated b from
131 Equation (1) and $b = 3$ for a sea cucumber of similar growth with $s.dx$, the logarithm of the
132 standard deviation of total length to the standard deviation of total weight ($s.dy$), b (the slope),
133 r^2 (coefficient of determination) and n (sample sizes) (Zar, 1996).

$$134 \quad t = [(s.dx) / (s.dy)] \times [(lb-3) / (\sqrt{1-r^2})] \times [\sqrt{n-2}] \quad (2)$$

135

136 **2.3 Life-history traits and population dynamic parameters of *Holothuria leucospilota***

137 **2.3.1 Structure of population and growth rates**

138 All biometric measurements from the nine different stations were pooled monthly, and
139 subsequently grouped into classes of three centimetres interval. Two methods were used to
140 analyse the data for growth rates (Method 1: Shepherd method and Method 2: ELEFAN
141 (Electronic Length Frequency Analysis) method).

142 Method 1: the data were analysed using FiSAT II (FAO-ICLARM Stock Assessment Tools,
143 www.fao.org/fi) using the Shepherd method (Gayanilo, Pauly & Parre, 2003).

144 Method 2: the estimation of the infinite length (L_{∞}) was obtained using Equation (3) and the
145 Maximum length of the sea cucumber (L_{max}) (Froese & Binohlan, 2000).

$$146 \quad \text{Log } L_{\infty} = 0.044 + 0.9841 * \text{Log } (L_{max}) \quad (3)$$

147 Growth rate was obtained by applying the ELEFAN method (optimization model), by using
148 the RStudio software with the TropFishR package (Mildenberger, Taylor & Wolff, 2017).

149 The optimum value of t_0 (time that length is zero) was calculated by the experimental formula
150 of Pauly equation (Equation (4)) with K , the growth factor (Froese & Binohlan, 2000).

$$151 \quad \text{Log } (-t_0) = - 0.3922 - 0.2752 \text{ Log } L_{\infty} - 1.038 \text{ Log } K \quad (4)$$

152 Comparisons of growth indices such as the infinite length (L_{∞}) and the growth factor (K)
153 were performed using the Equation (5).

$$154 \quad \Phi' = \text{Log } (K) + 2 \text{ Log } (L_{\infty}) \quad (5)$$

155 The maximum lifespan of this species was based on the following formula (Froese & Pauly,
156 2017; and Equation (6)).

$$157 \quad t_{\max} = t_0 + 3 / K \quad (6)$$

158

159 2.3.2 Mortality

160 Natural mortality (M) was calculated based on the Pauly Equation (7) (Sparre & Venema,
161 1998) with, M the annual natural mortality coefficient, L_{∞} the infinite length of the sea
162 cucumber (cm), K the growth curve parameter of the von Bertalanffy growth equation and T
163 (Celsius) is the mean environmental temperature (Sparre & Venema, 1998). The mean annual
164 temperature of the sea surface of north Oman Sea was estimated at 26 °C (Keymaram et al.,
165 2009).

$$166 \quad \text{Ln } (M) = - 0.0152 - 0.297 \text{ Ln } (L_{\infty}) + 0.654 \text{ Ln } (K) + 0.642 \text{ Ln } (T) \quad (7)$$

167 Total mortality (Z) was calculated based on the length-converted catch curves data. The
168 fishing mortality was estimated using the Equation (8), with Z , the total mortality, F , the
169 fishing mortality and M the natural mortality.

$$170 \quad F = Z - M \quad (8)$$

171 The exploitation rate (E), which is the ratio of fishing mortality to total mortality, was
172 calculated with the Equation (9) from Sparre & Venema (1998).

$$173 \quad E = F/Z \quad (9)$$

174

175 2.3.3 Recruitment and biomass

176 The relative yield per recruitment (Y/R) was estimated against the fishing mortality coefficient
177 or exploitation rate. In this Equation (10), E , is the exploitation coefficient, U , the exploitation
178 rate, M , the natural mortality coefficient, F , the fishing mortality coefficient and L_c (Length at
179 first capture) is the same as L_{c50} (Gayanilo, Pauly & Parre, 2003).

$$180 \quad Y/R = EU^{M/K} (-3 U / (1 + m) + 3 U^2 / (1 + 2m) + U^3 / (1 + 3m)) \text{ with}$$

$$181 \quad U = 1 - (L_c / L_\infty); m = (1 - E) / (M/K) = (K/Z); E = F/Z \quad (10)$$

182 In addition, the relative biomass per recruitment (B'/R) was calculated using the following
183 Equation (11).

$$184 \quad B'/R = Y'/R/F \quad (11)$$

185

186 2.3.4 The gonado-somatic index (GSI)

187 The maturity stages for male and female *Holothuria leucospilota* were determined
188 macroscopically using a 5-stage maturity key (Gaudron, Kohler & Conand, 2008). These
189 stages included: 'resting stage' (I), 'immature stage' (II), 'growing stage' (III), 'maturation
190 stage' (IV), 'post-spawning stage' (V). The gonado-somatic index (GSI) is expressing the
191 mean gonad weight as a proportion of a total body weight and was calculated using the
192 Equation (12), where GW , is the gonad weight and EW , is eviscerated body weight (Gaudron,
193 Kohler & Conand, 2008).

$$194 \quad GSI = GW/EW \quad (12)$$

195 Monthly data of sea temperature (in °C) were recorded in different stations (by multi-
196 parameter device, Hach ltd.) and used as a predicted environmental factor of the seasonal GSI .

197

198 2.3.5 Mean size at first sexual maturity (LM_{50})

199 The mean size at first sexual maturity (LM_{50}) was estimated for females by fitting the logistic
200 function to the proportion of mature sea cucumbers in 4-cm (TL) size categories (Equation
201 13) in which Y is the proportion of the number of all mature males and females to all
202 immature males and females in the same length class, X is the total length in cm and a and b
203 are correlation constants (King, 2007). The mean size at first maturity was taken when 50% of
204 individuals were mature.

$$205 Y = 1/1+\exp (-a-bX) \quad (13)$$

206

207 **2.4 Statistical analyses**

208 Comparison of population dynamic values with two methods (Method 1: Shepherd method
209 and Method 2: ELEFAN method) and between male and female lengths, and weights were
210 tested by Student Test (t -test) with paired t -test and independent t - test, respectively.

211 Correlation between temperature and GSI was tested by a Pearson correlation test. A Chi-
212 square test was used to assess sex ratio differences between males and females. Normality of
213 this data was assessed by using the Kolmogorov-Smirnov test. Data analyses were performed
214 using, FiSAT II and R Studio softwares (1.1.46) with the TropFishR package.

215

216 **3. Results**

217 **3.1 Length frequency distribution of *Holothuria leucospilota***

218 The mean \pm (min – max) deviation of total length and total weight for male (624 specimens)
219 and female (178 specimens) white threads fish were 31 ± 6 (18 – 45) cm, 31 ± 5 (19 – 43) cm
220 respectively, and, 770 ± 164 (370 – 1220) g, 762 ± 155 (375 – 1125) g respectively. The
221 differences between total length and total weight in both sexes were not significant ($p > 0.05$;
222 Student test). The length (TL) data were categorised into 3-cm groups which the highest
223 frequency (195 sea cucumbers) was belonging to individuals with 27 to 30 cm length (Fig.
224 3A).

225

226 3.2 Length-weight relationship of *Holothuria leucospilota*

227 The relationship between length and weight for *H. leucospilota* was calculated following the
228 Equation (1) and gave $a = 25.76$ and $b = 0.97$ ($R^2 = 0.61$) for females, and for males, $a =$
229 30.79 and $b = 0.92$ ($R^2 = 0.93$) and for both sexes $a = 24.93$ and $b = 0.98$ ($R^2 = 0.59$). The
230 Student test has shown significant differences between estimated b and $b = 3$ at the level of
231 0.05 (Fig. 3B), which means an allometric growth pattern (for both sexes) of *H. leucospilota*
232 in the northern waters of the Oman Sea.

233

234 3.3 Growth studies

235 The population dynamic parameters using the two methods (Shepherd and ELEFAN methods)
236 for males, females and both sexes of *Holothuria leucospilota* are detailed in Table 1. There
237 were no significant differences between the results of the two methods used ($p > 0.05$; t -test).
238 Growth parameters for both sexes together were estimated at $L_\infty = 50.5$ cm (with weight at
239 infinite: $W_\infty = a^* (L_\infty)^b = 1.211$ kg), $K = 0.51$ (yr^{-1}), and $t_0 = -0.27$. The growth curve (Fig.
240 4A) highlighted six cohorts and age groups and the growth performance index was estimated
241 at $\Phi = 3.11$. There was recruitment throughout the year and the highest rate of recruitment
242 was observed in winter and summer periods (Fig. 4B). Based on the results, the maximum
243 lifespan of this species was around 6 years (Fig. 5).

244

245 3.4 Mortality estimate

246 The natural mortality (M), fishing mortality (F) and total mortality (Z) were estimated at 0.94
247 (yr^{-1}), 0.56 (yr^{-1}), and 1.5 (yr^{-1}) respectively (Table 2). The exploitation coefficient (E) was
248 estimated at 0.36 (yr^{-1}) (Fig. 6). Based on the calculated parameters, the von Bertalanffy
249 equations for this species (length and weight) in the Northern Oman Sea (Iran) were as
250 follow:

$$251 L_t = 50.5 (1 - \exp(-0.51 (t + 0.27)))$$

$$252 W_t = 1211 (1 - \exp(-0.51 (t + 0.27)))^{0.98}$$

253

254 3.5 Yield and Biomass per Recruit

255 Based on length at first capture ($L_c = 27$ cm), which is 50% the probability of catching sea
256 cucumber, relative production per recruitment and relative biomass per recruitment were
257 estimated at $Y'/Rp = 0.02$ and $B'/Rp = 0.3$, respectively. Overall, the result demonstrated an
258 exploitation rate (U) of 0.28 and a fishing mortality at maximum sustainable yield (F_{msy})
259 equalled to 0.6 for this sea cucumber stock (Fig. 6).

260

261 **3.6 Sex ratio, gonad-somatic index (GSI) and size at first sexual maturity (LM_{50})**

262 From all sea cucumber sampled, 639 were males (75%) and only 223 were females
263 (25%). The sex ratio was significantly biased towards males (1 female/ 3 males) ($\text{Chi}^2 =$
264 100.38 , $p < 0.05$). The mean value of GSI for both sexes was 5.59 ± 1.75 . The highest GSI
265 values were observed in June ($21\% \pm 6$) and December ($8\% \pm 2$) and the lowest GSI value
266 was observed in August ($1\% \pm 0.5$) (Fig. 7). Moreover, there was no significant correlation
267 between the GSI and the monthly temperature (Pearson correlation, $p > 0.05$). Mean GSI and
268 maturity stage indicated that spawning time was during June and December. The mean size at
269 first sexual maturity (LM_{50}) was 246 mm for males, 220 mm for females and 225 mm for both
270 sexes (Fig. 8).

271

272 **4. Discussion**

273 A series of life-history traits and population dynamics values of the species *Holothuria*
274 *leucospilota* was evaluated with success and this is the first time in the study area despite an
275 economic and ecological importance. *H. leucospilota* is one of the economically valuable
276 species in the southern and northern Oman Sea (Iran). The Echinoderm phylum (including sea
277 cucumbers) plays a 'key role' in structuring marine ecosystems mainly in the organic matter
278 processing. The over-fishing of these sea cucumbers is likely to disturb the sustainability of
279 the targeted ecosystems (Uthicke, Schaffelke & Byrne, 2009).

280

281 **4.1 Life-history traits of *Holothuria leucospilota***

282 The length-weight (L-W) relationship has shown allometric growth with females heavier than
283 males for the same length group. It seems, growth curve (length and weight) of *H.*

284 *leucospilota* slows down after two years and allometric growth is common in sea cucumbers
285 (Herrero-Perezrul et al., 1999; Al-Rashdi, Claereboudt & Al-Busaidi, 2007; Chávez, de
286 Lourdes-Salgado & Palleiro, 2011; Dereli et al., 2016). The relationship between length and
287 weight for *H. tubulosa* species was calculated as, $W = 7.66 L^{1.06}$ ($R^2 = 0.52$) (Dereli et al.,
288 2016), for *Parastichopus parvimensis* species $W = 0.4 L^{1.83}$ (Chávez, De Lourdes-Salgado &
289 Palleiro, 2011), for *H. scabra* species $W = 0.0033 L^{2.17}$ ($R^2 = 0.80$) (Al-Rashdi, Claereboudt &
290 Al-Busaidi, 2007), for *Isostichopus fuscus* species $W = 1.14 L^{1.83}$ (Herrero-Perezrul et al.,
291 1999). In this study for *H. leucospilota*, the relationship between L-W is $W = 24.93 L^{0.98}$.
292 The L-W relationship is of great importance in fishery assessments (Haimovic & Velasco,
293 2000). Interestingly, it is well known that the functional regression ‘b’ value gives insights on
294 the body form, and it is directly related to the weight affected by ecological factors such as
295 temperature, food supply, spawning conditions and also other factors, such as sex, age, fishing
296 time, and area and fishing vessels (Ricker, 1973).

297 In the present study, *H. leucospilota* was shown to spawn twice a year with a major peak in
298 June and a weaker peak in December. Spawning events were not correlated with an increase
299 or a decrease of temperature. Greater percentages of new recruits also support spawning
300 events in winter and in summer periods. Spawning period of *H. leucospilota* was reported
301 from November to April in Australia (Franklin, 1980), from November to March in Cook
302 Islands (Drumm & Loneragan, 2005), from June to September in Taiwan (Choo, 2008), in
303 February and in May in Indian Ocean (Conand, 2008), in February and in May in the Western
304 Indian (Gaudron, Kohler & Conand, 2008), and, from June to October in Daya Bay in China
305 (Huang et al., 2018). The differences in spawning periods of any species are affected by
306 environmental conditions. In tropical regions, almost shallow-water holothurians have an
307 annual of 2- to 3-months spawning period during the warmer months of the year. The
308 holothurians have different reproductive patterns and need to be studied in each region (Chao,
309 Chen & Alexander, 1995). The sea cucumber reproduction cycle differs among species and
310 even within a species distributed in different regions (Huang et al., 2018).

311 The size at first sexual maturity (LM_{50}) for white threads fish was estimated at 246 mm for
312 males and 220 mm for females. Females seem to get mature earlier; therefore their growth
313 might be slower than that of males, as a result of a higher energy involved earlier into
314 reproduction instead of growth. Therefore, females *H. leucospilota* have a length at infinite
315 (L_{∞}) smaller than that of males. The LM_{50} of *H. sanctori* was 201 to 210 mm in the eastern
316 Atlantic in Spain (cited in Conand, 1993). For *H. atra*, LM_{50} was 165 mm for males and 155

317 mm for females in Egypt (Abdel_Razek et al., 2005). The size at first maturity is an important
318 parameter for managing a stock of a commercial species, as it helps to limit capture sizes
319 (Conand, 2008) and it is used as a tools for enhancing sustainable management in fisheries
320 (Kohler, Gaudron & Conand, 2009). This parameter is needed for fisheries management,
321 conservation of exploited sea cucumbers and small immature individuals' collection decreases
322 for sustainability of the population.

323

324 **4.2 Population dynamic of *Holothuria leucospilota***

325 Comparison of the population parameters of *H. leucospilota* from the present study with those
326 of other studies in different parts of the world (Table 2) has shown that infinite length and
327 growth coefficient of females from different species are generally smaller than those of males
328 from respective species. Moreover, the infinite length and growth coefficient of different
329 species change from region to region (Table 2). Differences in the range of the infinite length
330 and growth rate are influenced by the ecological differences of each region (King, 2007). The
331 growth rate (K) is expected to be higher in the tropical regions. Higher K values for species
332 are common in tropical waters. Holothurians are ectotherms and their metabolic rate increase
333 with higher temperature until a threshold (Hashemi et al., 2015). In general, the difference in
334 the infinite length and growth rate from one region to another region might be due to the
335 quantity and quality of food and climatic conditions (Bartulovic et al., 2004). Various factors
336 can also affect holothurians growth including age, sex, season, year, type of feeding
337 behaviour, physiological conditions, differences in food availability and reproductive period
338 (Lalèyè, 2006). Mean of growth performance index (Φ') was found to be equalled to 3.11
339 (Table 2). The comparison of Φ' values of growth curves is necessary to understand the
340 correlation between the infinite length and the growth rate. A growth curve has a growth rate
341 that holds constant changes at different times and for different sizes. Differences in ecological
342 conditions and latitude changes can affect the values of infinite length and growth rate (King,
343 2007).

344 The natural mortality rate of *H. Leucospilota* in this study was higher than that of fishing
345 mortality. The ratio of fishing mortality to maximum sustainable yield named as the
346 exploitation coefficient ($F/FMSY$) was less than one. If this value is more than 1, it indicates
347 that there is over-fishing (Arrizabalaga, Murua & Majkowski, 2012). In this present study, the
348 exploitation coefficient was less than 0.5, indicating that the amount of capture from fisheries

349 was not more than the optimum level. Both exploitation coefficient and exploitation rate
350 should not be greater than 0.5 or, the fishing mortality should not exceed natural mortality
351 otherwise it indicates over-fishing (Sparre & Venema, 1998; King, 2007). The most important
352 factors affecting the pressure on stocks are, first, the amount of catch and harvesting of a
353 stock, and second, the environmental factors that affect survival and access to the fishery
354 resources (Mateus & Estupinan, 2002).

355

356 **4.3 Management and conservation of the species in the Oman Sea**

357 It is recommended that appropriate instructions need to be established for the harvesting and
358 management of *Holothuria leucospilota* species in the Oman Sea. Harvesting of the white
359 threads fish should not occur in winter and in summer during spawning periods. The size of
360 capture should be greater than 250 mm as it is known that size at first maturity is an important
361 parameter for managing stock (Conand, 2008). This parameter is needed for fisheries
362 management, conservation of exploited sea cucumbers and small immature individuals'
363 collection decreases for sustainability of population. The present study has demonstrated that
364 the stock of *H. leucospilota* has not yet reached an 'overfished' status. The results of the
365 present study could help in the management of the exploitation of *H. leucospilota* population
366 and its sustainability with the establishment of a harvesting period and a size limit capture.

367

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374 **Conflict of interests**

375 The authors declare no conflict of interests.

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511 **Tables**

512 **Table 1.** Comparison of population dynamics values of *Holothuria leucospilota* with two
 513 methods (Shepherd method (1) and ELEFAN method (2)) (L_{∞} = infinite length; K = Growth
 514 rate; t_0 = time that length is zero; Φ' = Growth performance index; M = Natural mortality; F =
 515 Fishing, mortality; Z = Total mortality; E = Exploitation rate).

Species (sex)	Method	L_{∞} (cm)	K (yr^{-1})	t_0	Φ'	M	F	Z	E
<i>Holothuria leucospilota</i> (male)	(1)	49	0.6	-0.28	3.09	0.95	0.64	1.59	0.4

<i>H. leucospilota</i> (female)	(1)	47	0.45	-0.28	3.09	0.95	0.64	1.59	0.4
<i>H. leucospilota</i> (Total)	(1)	49	0.5	-0.28	3.09	0.95	0.64	1.59	0.4
<i>H. leucospilota</i> (male)	(2)	56	0.54	-0.26	3.13	1	0.4	1.4	0.29
<i>H. leucospilota</i> (female)	(2)	50	0.44	-0.31	3.15	0.84	0.71	1.55	0.46
<i>H. leucospilota</i> (Total)	(2)	52	0.54	-0.25	3.14	0.95	0.35	1.3	0.26
<i>H. leucospilota</i> (Total)	Mean of (1) + (2)	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

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522 **Table 2.** Comparison of population dynamic values of *Holothuria leucospilota* with other
523 studies around the world. For details of the abbreviation name of the values see Table 1.

Species / Region	L_{∞} (cm)	K (yr^{-1})	t_0	Φ'	M	F	Z	E	References
<i>Isostichopus</i> <i>fuscus</i> / Galapagos Islands, Ecuador	36.11	0.18	-	-	0.51	-	-	-	Herrero-Perezrul et al., 1999
<i>Parastichopus</i> <i>parvimensis</i> / California, USA	50	0.6	-0.10	3.2	0.85	-	-	-	Chávez, De Lourdes-Salgado & Palleiro, 2011

<i>I. badionotus</i> / Yucatan, Mexico	40.3	0.25	-0.18	-	0.38	0.5	0.88	0.54	De Jesús-Navarrete, Poot & Medina- Quej, 2018
<i>Holothuria</i> <i>leucospilota</i> / Oman Sea Iran	50.5	0.51	-0.27	3.11	0.94	0.56	1.50	0.36	Present study

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538 **Figure legends**

539 **Figure 1.** Map of *Holothuria leucospilota* sampling stations in the northern Oman Sea (Iran).

540 **Figure 2.** Biometric measurements of *Holothuria leucospilota* (White threadfish) in the
541 Northern Oman Sea (Iran).

542 **Figure 3.** Length and frequency (A) and Length-Weight relationship (B) of all collected
543 *Holothuria leucospilota* in the northern Oman Sea (Iran).

544 **Figure 4.** Growth curve and monthly recruitment in percentage derived from the structure of
545 population of *Holothuria leucospilota* from the northern Oman Sea (Iran). (A) The growth
546 curve plot shows reconstructed frequencies, with negative and positive values as white and
547 black coloured histograms, respectively. The background shading shows runs of peaks, with
548 positive peaks in blue, negative peaks in pink, and values of zero in white. The different
549 colour backgrounds were added in order to help visualising sign and magnitude of the bin
550 values. The sum of all positive peaks is called the ‘available sum of peaks’ (ASP), which
551 represents a maximum possible score. The ‘estimated sum of peaks’ (ESP) is the sum of peak
552 values crossed by the growth curves (Pauly, 1985).

553 **Figure 5.** (A) Exploitation coefficient curve and (B) Relative Yield per Recruit (Y/R) and
554 Relative Biomass per Recruit (B/R) of *Holothuria leucospilota* in the northern Oman Sea
555 with FMSY (Fishing mortality rate of maximum sustainable yield), F0.5 (fishing mortality
556 rate at which the slope of the yield-per-recruit curve is only half the slope of the curve at its
557 origin) and, F0.01 (fishing mortality rate at which the slope of the yield-per-recruit curve is
558 only one percent the slope of the curve at its origin).

559 **Figure 6.** Monthly variation of the gonado-somatic index (GSI) (male and female) of
560 *Holothuria leucospilota* and temperature (Temp.) in the northern Oman Sea (Iran).

561 **Figure 7.** The size at first sexual maturity (LM_{50}) (males (above) and females (below)) of
562 *Holothuria leucospilota* in the northern Oman Sea (Iran).

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