

Growth Parameters, Mortality and Optimal Exploitation of the Rock Fissures of *Panulirus Homarus megasculptus* in the Water's Coast of Hadhramout – Yemen

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Abstract: This study aimed to evaluate selected biological parameters and population dynamics of the scalloped spiny lobster, *Panulirus homarus megasculptus* (*P. h. megasculptus*), along the Hadhramout coast during the period from October 2023 to February 2024, in order to contribute to filling the gap in biological information required for the sustainable management of its fishery. 1,040 specimens were analyzed to estimate sex ratio, growth parameters, mortality and exploitation rates, length at first capture (Lc), length at first sexual maturity (Lm), and relative yield per recruit (Y/R). The results indicated a balanced sex ratio between males and females. Moreover, the majority of the captured individuals were below the legal minimum size for harvesting. Growth parameters estimated using the ELEFAN method revealed a moderate growth pattern for the studied population, with a growth coefficient of $K = 0.49 \text{ year}^{-1}$. Natural mortality ($M = 1.28 \text{ year}^{-1}$) was higher than fishing mortality ($F = 0.28 \text{ year}^{-1}$), resulting in a low exploitation rate ($E = 0.18$), which suggests that the stock is currently underexploited. The length at first capture was estimated at $L_c = 76 \text{ mm}$, while the length at first sexual maturity was $L_m = 66.9 \text{ mm}$. The relative yield per recruit was estimated at $Y/R = 0.57$. These findings indicate the potential for increasing the exploitation of *P. h. megasculptus* within the framework of sound fisheries management, provided that the legal minimum size limit is strictly enforced, thereby ensuring resource sustainability and the conservation of the natural stock along the Hadhramout coast.

Keywords: Exploitation; Growth; Hadhramout coast; Mortality; Rock fissures; Sex ratio.

1. Introduction

The rock lobster (*Panulirus homarus*) is found in the shallow waters of the Hadhramout and Al Mahrah coasts, the Gulf of Aden, and Socotra Island in the Indian Ocean [1]. The rock lobster caught off the coast of Hadhramout, Yemen, is the subspecies *P. h. megasculptus*. It belongs to the family Palinuridae, genus *Panulirus*, and is widespread along the Yemeni and Omani coasts, extending to the southeastern coast of Iran. It lives in shallow waters, usually at a depth of 1 to 5 meters, among the rocks in the wave zone, and sometimes its depth can reach 90

meters.[2].[3].[4]. The rock lobster *P. h. megasculptus* is an important economic resource and commercial commodity in the waters of the Hadhramout coast. It is one of the fishing targets for fishermen because its price is very high, which leads to a high density of fishing and the catching of large sizes, which leads to a lack of knowledge of stock management and a lack of control over fishing density. This causes the average size of the lobsters caught to become smaller, and the smaller the size, the lower its economic value. Biological studies on this species on the eastern coast of Yemen are few and outdated and need updating of

biological data [5].[6].[7] and [8]. Due to the lack of studies on the biological aspects of rock squirts, especially with regard to growth, mortality rate, exploitation, length at capture and at sexual maturity, to ensure the sustainability of its traps. This study aimed to determine the growth of rock

lobsters, mortality rates, exploitation, length at capture and at sexual maturity. The results of this research are expected to provide a new database for the management of rock lobster fisheries in the waters of the Hadhramout coast.

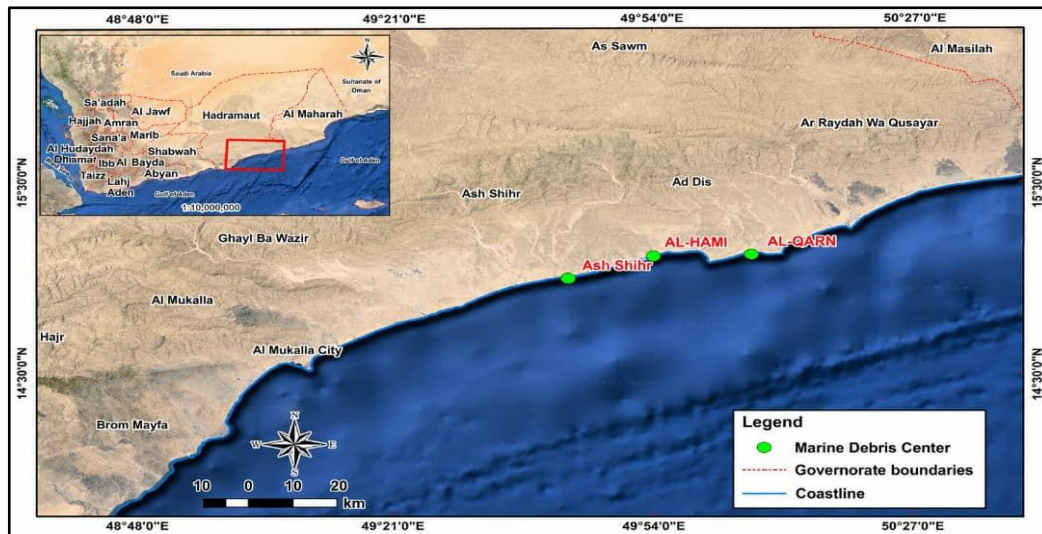


Figure 1. Map of the study sites where *P. h. megasculptus* rock-fracture samples were collected.

2. Materials and Methods

2.1 Study location

The Hadhramout Governorate lies between (14°30'-14°56' N and 21°50'49' E), with a coastline of approximately 750 km. This represents a portion of the Yemeni coastline. The study encompassed three sites on the Hadhramout coast: Al-Shihr, Al-Hami, and Al-Qarn. Figure.1 shows the Map of the study sites where *P. h. megasculptus* rock-fracture samples were collected.

2.2 Sampling collection

The target species for this study was determined based on the Yemeni fisheries manual [9-11]. To conduct this study, 1040 specimens were collected (503 males and 537

females). Biological data related to sex, shell length, and total weight were obtained through random sampling from fishermen at the following landing centers: Al-Shihr, Al-Hami, Al-Qarn, where sample data was recorded every four days of each week during the study period from October (2023 to February 2024). This is the period of the rock lobster fishing season on the Hadhramout coast. The data collected included sex determination, shell length (CL) and total weight (W), where the sex of the rock lobster *P. h. megasculptus* was visually distinguished based on differences in the reproductive organs, the fifth leg end, and the external feathers in the abdominal region (Figure 2) [12-13].

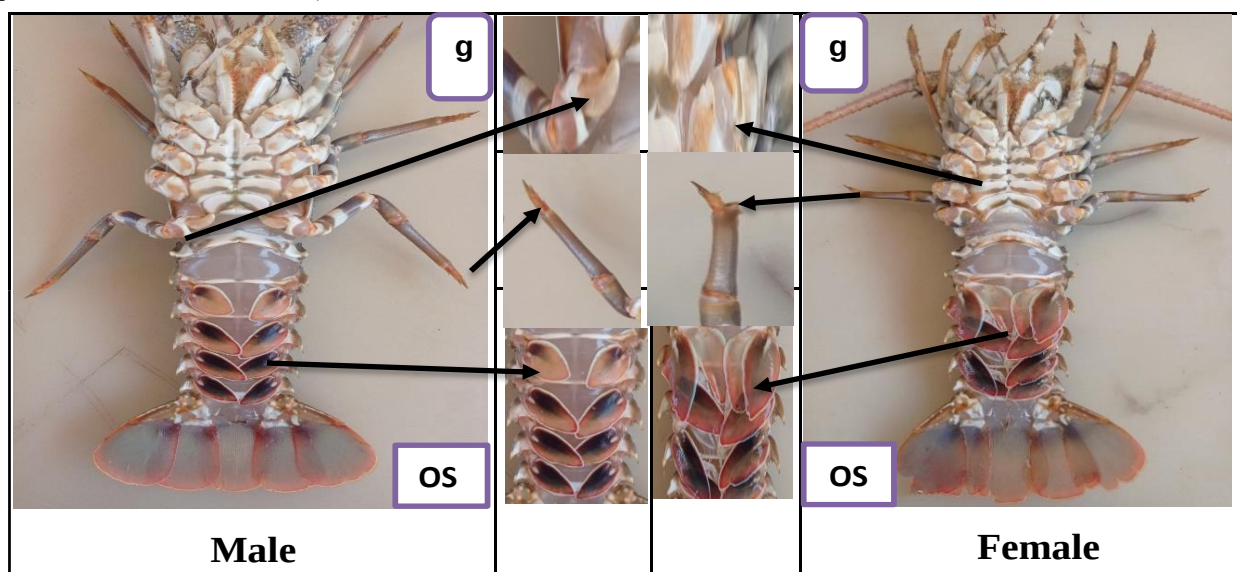


Figure 2. Secondary sexual characters of *P. h. megasculptus* male, female, g = gonophore, os = ovigerous setae, ewl5 = end of walking legs 5th

Shell length was used as a measure of length in this study. The shell length of each specimen was measured precisely from the mid-dorsal edge between the anterior spines to the edge of the posterior shield using calipers and vernier scales to the nearest 0.1 mm, and the total weight of each specimen was measured using a digital scale to the nearest 0.1 g. [14]. Figure 2 illustrates the secondary sexual characters of *P. h. megasculptus* in males and females.

2.3 Data Analysis

The sex ratio (comparing the number of male to female of *P. h. megasculptus*) was calculated and then chi-squared analysis was applied to test it using the following formula. [15]. Where "O" refers to the value of observation, "E" refers to the value of expectations.

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Shell longitudinal frequency data for all the rock lobster *P. h. megasculptus* specimens were analyzed using the Bhattacharya. [16]. method in FiSAT software [17]. Growth estimates were obtained, where infinite length ∞L and growth constant K represent the infinite length, using the ELEFAN I method included in the FiSAT software [18]. Theoretical age Δt was estimated using the Pauly [19].method, and the growth index $\emptyset$ was estimated according to the Pauly and Munru [20] formula. The Beverton and.[21]. method, the Jones and Van Zalinge method [22], and the Pauly.[23]. linear catch curve method were used to estimate total mortality (Z), and total natural mortality (M) was calculated using three methods: Pauly M Equatiob.[24] Efanovs, [25]. and Pauly [24].formula using annual average water temperature data, and the fishery mortality rate was calculated according to the equation $F=Z-M$ (Pauly,) [24]. while the exploitation rate (E) was calculated from the ratio F/Z (Pauly,) [19]. and (E.max) was estimated by the longitudinal transformed fishery curve method using the ELEFAN model. Length at first capture (Lc) and length at first sexual maturity (Lm) were estimated by analyzing the catch curve using the method of Pauly[19]. and [26]. The relative return per recruit was estimated using the Beverton and Holt analysis in the FiSAT software, according to Pauly and Soriano [27].

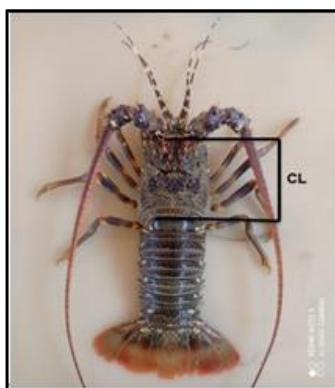


Figure 3. Schematic representation of the shell length measurement of *P. h. megasculptus* collected for the current study.

3. Results

The statistical analysis of the sex ratio in the *P. h. megasculptus* showed that the total sample size was 1040

individuals, comprising 503 males and 537 females. The male ratio was 48% and the female ratio was 52%. When testing for gender differences using the chi-square test based on the expected biological ratio of 1:1, the calculated value was 1.11, which is less than the tabulated value of 3.84, at a significance level of (0.05). This indicates no significant differences between the sexes. Therefore, the studied samples follow a natural sexual balance, as the estimated sex ratio (1:1.07) reflects biological stability and the absence of a clear bias towards either sex. Table 1 shows the ratio of *P. h. megasculptus* (males to females) during the study period and the value of the chi-square test.

Table 1. Male-to-female ratio of *P. h. megasculptus* during the study period and corresponding (χ^2) test values.

Months	Total number	Male s	Female s	Expected percentag e	Calculate d χ^2	χ^2 Tabular y at (0.05)	Result
October 2023	112	48	64	1:1.33	2.00	3.84	(Acceptanc e H_0), no significant differences
November 2023	225	113	112	1:0.99	0.00	3.84	(Acceptanc e H_0), no significant differences
December 2023	476	238	238	1:1.00	0.00	3.84	(Acceptanc e H_0), no significant differences
January 2024	116	58	58	1:1.00	0.00	3.84	(Acceptanc e H_0), no significant differences
February 2024	111	46	65	1:1.41	3.27	3.84	(Acceptanc e H_0), no significant differences
Grand total	1040	503	537	1:1.07	1.07	3.84	(Acceptanc e H_0), no significant differences

3.1 Growth coefficient

Based on shell length frequency analysis using the Bhattacharya method (1967), the growth coefficients for *P. h. megasculptus* (males, females, and both sexes) combined were estimated for the following values: (L_∞ , K, to, $\emptyset$). Table (2) shows that the value of infinite length (L_∞) and the growth rate K were derived from the EIEFAN plot. Figure 4 shows the ELEFAN K-scan results for *P. h. megasculptus*, highlighting the optimal growth coefficient (K) estimated from the length-frequency data.

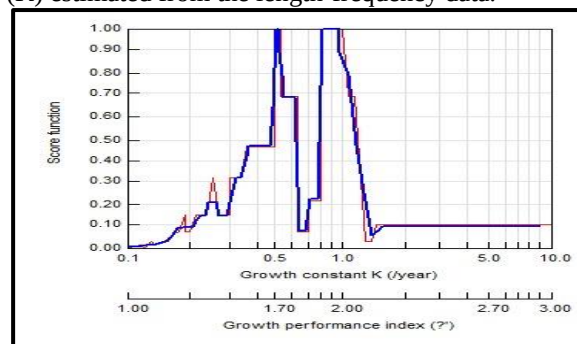


Figure 4. ELEFAN K-value survey model for *P. h. megasculptus* on the Hadhramout.

The theoretical age at zero length was also estimated as $t_0 = -0.94$. The growth performance index in terms of length growth for the rock lobster *P. h. megasculptus* was calculated, yielding a value of $\emptyset = 3.7$, which is relatively high. It was also found that the growth coefficient of females is higher than that of males, despite females

reaching a lower asymptotic length than males. Table 2 summarizes the von Bertalanffy growth coefficients obtained for *P. h. megasculptus* from the Hadramout coast, Yemen.

Table 2. Von Bertalanffy growth coefficients for *P. h. megasculptus* from Hadramout, Yemen.

Growth parameters of <i>P.h.megasculptus</i>				
Gender factor	L_{∞}	K	t_0	$\emptyset$
Males	89.4	0.17	-	-
Females	85.1	0.21	-	-
Both	101.3 mm	0.49	-0.94	3.7

3.2 Mortality and Exploitation Rate

The results of this study indicated that the natural mortality rate was higher than the hunting mortality rate. The mean total estimate of natural mortality was $M=1.28$, and the mean total estimate of overall mortality was $Z=1.56$ (Figure.5). Fishing mortality was calculated as $F=0.28$, and the exploitation rate was $E=0.18$ with $E_{max}=68$. The optimal exploitation rate should now not exceed $E=0.50$. The value of E indicates that the catch for rock lobster *P. h. megasculptus* in the study area is underutilized.

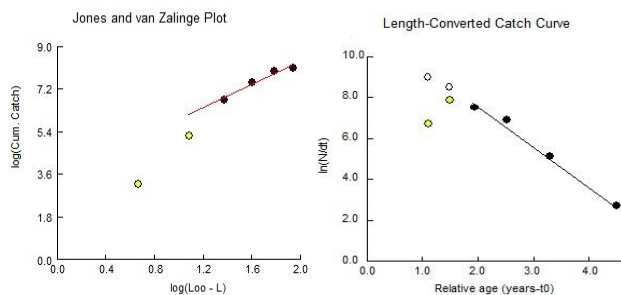


Figure 5. Estimate of the total mortality rate (Z) of *P. h. megasculptus* from the Hadramout coast, Yemen, based on the length-converted catch curve.

3.3 Length at capture and at sexual maturity

The results of the capture curve analysis for the rock lobster *P. h. megasculptus* showed that the size at capture L_c was estimated at (76 mm), while its size at sexual maturity was estimated at ($L_m = 66.9$ mm). The shell length at first capture (L_c) of *P. h. megasculptus* in the waters of the Hadramout coast, Yemen, is illustrated in Figure 6.

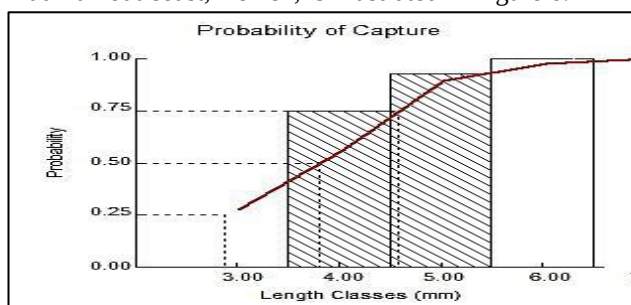


Figure 6. Shell length at the first catch of *P. h. megasculptus* homarus in the waters of the Hadramout coast – Yemen.

3.4 Relative return per recruit

Y/R was estimated by deriving (L_c/L_{∞}) , where the relative yield was ($Y/R = 0.57$). A higher value for Y/R was obtained at $E_{max} = 68$. Although the value of E is less than the maximum level of (Y/R) for rock fractures, at the same time the exploitation rate E was smaller than the value that maintains the vital value (B'/R), as shown in Figure 7.

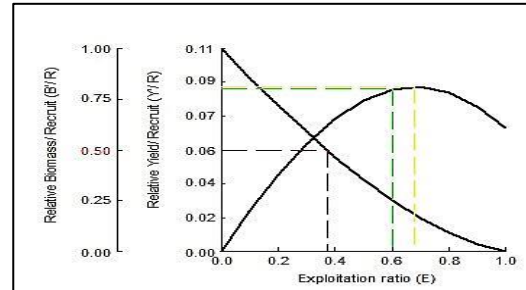


Figure 7. Yield-per-recruit (Y/R) and biomass-per-recruit (B'/R) versus exploitation rate for *P. h. megasculptus* from Hadramout, Yemen.

4. Discussion

The results of the current study showed that the average shell length for all rock *P. h. megasculptus* samples from the Hadramout coast was (62.15 mm). Males of *P. h. megasculptus* exhibited a greater shell length compared with females. The shell lengths recorded in the present study differed from those reported in other regions. In Oman, the shell length of the same species ranged from 37 to 134 mm [28] and from 24 to 151 mm [14], while on the Iranian coast it ranged from 46 to 71 mm [29]. However, the results of the current study were consistent with those reported by [30] in Indonesia, where shell lengths ranged from 41 to 94 mm.

Table 3. Biological parameters of *P. h. megasculptus* from Hadramout, Yemen.

Region	L_{∞}	K	t_0	$\emptyset$	References
Yemen	♂ 136	0.46	-	-	[6]
	♀ 118	0.44	-	-	
	225 TL	0.45	-	-	
Somalia	127 ♂	0.46	-0.61	-	[49]
	110 ♀	0.44	-0.53	-	
Kenya	♂ 115	0.25	-	-	[50]
	♀ 105	0.29	-	-	
Oman	128.9	0.33	-0.35	-	[38]
Iran	103	0.57	-	8.69	[35]
Oman	144.8 ♂	72	-	4.191	[28]
	134.7 ♀	81	-	4.157	
	134.2	71	-	4.163	
India	119.4	0.30	0.009-	-	[40]
Indonesia	113.9 ♂	0.22	-0.53	-	[44]
	91.1 ♀	0.42	-0.29	-	
Yemen	♂ 89.4	0.17	-	-	Current study
	♀ 85.1	0.21	-	-	
	101.3	0.49	-0.94	3.7	

The size of the rock *P. h. megasculptus* may vary from region to region due to several factors, including differing environmental conditions and continuous fishing pressure [31]. The results of the current study showed that the sex ratio of *P. h. megasculptus* in the Hadhramout coast is generally balanced, with a slight dominance of females in some months, and the sex ratio between the sexes may change over time as a result of the high mortality rate and low growth rate [32], and the equal ratio between males and females indicates that their chances of being caught are equal [33]. Sex balance is also crucial for ensuring the reproduction of the species, along with adequate food availability, which maintains the stability of *P. h. megasculptus* [34]. The results of the current study are consistent with previous studies conducted which indicate that *P. h. megasculptus* populations. They are often sexually balanced and close to a 1:1 ratio, especially in areas where there is no selective hunting pressure on one sex [35],[36].

Table 4. Comparison of growth parameters for *P. homarus* in different regions.

Region	Z	M	F	E	References
Yemen	2.33 ♂	0.63-1.44	1.25	0.6	[6]
	2.04 ♀	-0.85			
	2.1	-			
Srilanka	2.10 ♂	0.98	1.12	0.53	[51]
	1.60 ♀	0.92	0.68	0.43	
Oman	4.1 ♂	95	3.16	78	[28]
	4.67 ♀	95	3.81	0.8	
India	2.52	0.67	1.84	0.73	[40]
Indonesia	1.74	0.58	1.16	0.67	[52]
Indonesia	0.2823	0.2655	0.167	0.595	[46]
Yemen	1.56	1.28	0.28	0.18	Current study

The results of the annual growth coefficient for both sexes showed an average growth of *P. h. megasculptus* is ($K=0.49$) in the Hadhramout coast. The result of the current study agrees with [28, 31, 37-41]. The study indicated that the growth rate (K) of the studied species in Yemeni waters was similar to that of other coastal areas, ranging between (30 and 71 mm). The growth factor results for males and females of *P. h. megasculptus* were estimated at ($L_{\infty}=85.1$, $K=0.21$), and ($L_{\infty}=89.4$, $k=0.17/\text{years}$), respectively, with females showing higher growth than males despite reaching shorter final lengths. The result of this study agrees with the results of studies in other regions. [42-44]. The infinite length of the sexes was estimated to be ($L_{\infty}=101.3$ mm). This is close to the value estimated for the same species on the coasts of Iran, where it was found [39]. ($L_{\infty}=103/\text{year}$). However, it differs from the values recorded in Oman and Indonesia (Table 3). The growth performance index (Φ) for the rock lobster *P. h. megasculptus*. showed a value of $\Phi = 3.7$. This result is largely consistent with the normal range of growth performance indices reported for

crustaceans and *Panulirus homarus*. which was estimated at 2.5–3.5 [20]. However, the result of this study differs from those reported in Iran [39] and Oman [28] where a very high growth performance was observed for *P. h. megasculptus*. The findings of this study indicate that *P. h. megasculptus* exhibits a relatively high growth rate, which may be attributed to favorable environmental conditions or adequate food availability in the study area. The growth performance index is used as a tool to measure differences between regions and different fishing seasons [45]. Mortality is caused by either human or natural activities and does not contribute to the sustainability of the catch, as the total mortality reached ($Z=1.56$) annually, which is the sum of the value of natural mortality ($M=1.28$) and the mortality resulting from fishing, which amounted to ($F=0.28$) annually. The study results indicate that the natural mortality rate (M) is high and constituted the largest proportion of total deaths (Z). [19]. stated that the natural mortality rate is considered high if it exceeds 1.5 years. Natural mortality occurs due to several factors, including predation, disease, and food availability. It is also linked to environmental factors. Mortality rates for the same species may vary in different waters depending on competition and predation intensity [46]. Table 4 compares the mortality (Z , M , and F) and exploitation (E) rates of *P. h. megasculptus* reported from different regions, highlighting the variability of these parameters among geographical locations. The exploitation rate (E) is an important indicator for assessing the stock status of a species in the catch. This study recorded an exploitation rate ($E = 0.18$), which is much lower than the critical level. This reflects limited exploitation and low pressure, requiring increased fishing effort, which may contribute to stock stability and maintain ecological balance in the medium term. The optimal stock exploitation value is typically around ($E=0.5$) [24]. Knowing the length at sexual maturity (L_m) is crucial in determining the permissible catch size, and the value of L_m has been estimated. In this study, the catch size is less than the first (LC) size, indicating that most rock lobsters reach sexual maturity before being caught. According to [31]. The catch condition is good when the size at capture is equal to or greater than the size at sexual maturity. Individuals of the *P. h. megasculptus* reach sexual maturity when their shell length reaches (66.9 mm). This result agrees with the findings of other studies on the same species, where [5].estimated the length of first sexual maturity on the Yemeni coast to be (60-70 mm), while in neighboring areas the estimated length was (65-80 mm) [38],[47]. It is affected by factors such as growth and time, and environmental factors such as temperature and food quality have influenced size at first sexual maturity [48]. The relative return per recruit was calculated in this study, with the value estimated at (0.57). The utilization ratio (E) should be maintained below the point that achieves maximum productivity to ensure the sustainability of the stock.

5. Conclusion

P. h. megasculptus is available along the eastern coast of Hadhramout Governorate and constitutes a highly valuable commercial resource. Its increasing economic value has encouraged unregulated exploitation. Assessing rock lobster

fisheries remains challenging due to the lack of an up-to-date database. In this study, a more accurate approach to catch data collection was employed by recording information directly from the targeted landing centers.

The study aimed to determine sex ratio, growth, mortality and exploitation rates, as well as size at first capture and size at first maturity. To estimate the relative yield per recruit during the fishing season, the results were analyzed using the FiSAT II software. It was observed that the majority of the sampled individuals were very small in size. To ensure the sustainability of the stock, these individuals should be allowed sufficient time to grow until they reach an appropriate harvestable size.

The findings of this study can contribute to the effective management of rock lobster fisheries and support the sustainable exploitation of this commercially important species along the Hadhramout coast.

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معاملات النمو، الوفيات والاستغلال الأمثل للشروخ الصخري *Panulirus homarus* في مياه ساحل حضرموت – اليمن

المخلص: استهدفت الدراسة معرفة بعض المعلمات البيولوجية والديناميكا السكانية للشروخ الصخري *Panulirus homarus megasculptus* في مياه ساحل حضرموت خلال المدة من أكتوبر 2023 إلى فبراير 2024م، وذلك للإسهام في وضع البيانات البيولوجية اللازمة لإدارة مصائد الشروخ الصخري بصورة مستدامة. استندت الدراسة إلى تحليل 1040 عينة، وشملت تقدير نسبة الجنس، ومعلمات النمو، ومعدلات النفوق والاستغلال، والطول عند الاصطياد الأول والطول عند النضج الجنسي الأول، بالإضافة إلى العائد النسبي لكل مجند. أظهرت النتائج توازناً في نسبة الجنس بين الذكور والإناث، كما بينت أن معظم الأفراد المصطادة كانت دون الحجم القانوني للصيد. وأظهرت معلمات النمو المقدرة بطريقة ELEFAN نمواً متوسطاً للنوع المدروس، حيث بلغت قيمة معامل النمو $K=0.49$ سنة⁻¹ (كما كانت الوفيات الطبيعية $M=1.28$ سنة⁻¹ (أعلى من وفيات الصيد $F=0.28$ سنة⁻¹، مما انعكس على انخفاض معدل الاستغلال $E=0.18$) وأوضح أن المخزون غير مستغل بصورة كاملة. وبلغ الطول عند الاصطياد الأول $L_c=76$ مم (والطول عند النضج الجنسي الأول $L_m=66.9$ مم، بينما بلغ العائد النسبي لكل مجند $Y/R=0.57$) وأوصت الدراسة برفع معدل استغلال الشروخ الصخري في ضمن الاستغلال الأمثل، مع الالتزام بالحجم القانوني للصيد، وبما يضمن استدامة المورد والمحافظة على المخزون السمكي في سواحل حضرموت.

الكلمات المفتاحية: الشروخ الصخري، نسبة الجنس، النمو، الوفيات، الاستغلال، سواحل حضرموت.