



Original Research Article

Growth patterns and exploitation status of the spiny lobster species *Palinurus mauritanicus* (Gruvel 1911) in Mauritanian coasts

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Amadou Sow¹,
Bilassé Zongo*²
and
T. Jean André Kabre²

¹Institut Mauritanien des
Recherches Océanographiques et
des Pêches (IMROP), Mauritanie

²Université Nazi Boni, LaRFPF,
Burkina Faso

*Corresponding Author
Email: azongo@hotmail.fr

In the Mauritanian coasts, fishing effort on *Palinurus mauritanicus* contributes in the decline of the stock. From February to August 2015, samplings were carried out monthly in order to study the growth patterns and the stock status to provide further information for sustainable management and exploitation of the species. A total of 12008 individuals were collected. Total length (Lt) and cephalothoracic length (Lc) were measured with a vernier caliper. The species were separately weighed on a digital balance and their sex noted. The collected data were entered on excel spreadsheet in order to analyse growth kinetics, exploitation kinetics and estimate fish mortality using FISAT II software. Male of *P. mauritanicus* had an average Lc = 130 mm and an average Lc = 111 mm. The annual length frequency distribution gave respectively 6 and 7 age-groups for females and males. Lc-Lt relationship and Lc-Wt relationship showed a minor allometry ($b < 3$ for both). The linear growth evaluation (Elefan I method), showed that the maximum cephalothoracic length ($L_{c\infty}$) = 199.5 mm, $k = 0.22$ for females, $L_{c\infty} = 220.5$ mm, $k = 0.32$ for males, and $L_{c\infty} = 220.5$ mm, $k = 0.21$ for both sexes. With a total mortality (Z) = 1.35year^{-1} , males were more vulnerable than females with respectively an exploitation rate (E) = 0.82 and 0.79. The mortality rates and the relative Recruit Yield (Y/R) indicate that the stock is in a level of overfishing. Efforts need to be considered for the recovery of *P. mauritanicus* population.

Key words: Spiny lobster, Palinuridae family, growth parameters, exploitation, Mauritanian coasts.

INTRODUCTION

P. mauritanicus (lobster species) occurs along the Western coasts of Africa and Europe from Senegal to the Western coasts of Ireland, and throughout the Mediterranean Sea (Minchin, 1989; Palero and Abelló, 2007). The species recorded in coastal Atlantic areas off Northwest Africa, with scattered occasional records in the Mediterranean Sea (Galil et al., 2002; Guerao et al. 2006), is a high economic value species (Bensahla et al., 2016) and fished commercially off Mauritania and the Sahara. The lobster

fishery was initiated by Camaret fishermen around 1956 following the decadence of fishing for green lobster (Maigret, 1978). Initiated at the beginning by traps, fishing is currently carried out using gillnets and landings are made at Nouadhibou.

According to Diop (1990), the pink lobster fishery had 3 phases between 1963 and 1988. A phase of overexploitation between 1963 and 1971, a reconstitution phase between 1971 and 1987 and another phase of

overexploitation between 1987 and 1988. To the industrial fishing is mainly coupled to the artisanal one (Mahfoud et al., 2018) and both efforts exploit a large quantity of pink lobster. During the overexploitation period between 1963 and 1971, 63 boats were used for more than 12000 days of fishing. For replenishment, the fleets are reduced to 10 boats developing a steady effort with about 2000 fishing days until 1987 (Diop and Kojemiakine, 1990). From 1987 there was again an increase in the number of boats and the effort of fishing which have more than doubled on the species. Nowadays, *P. mauritanicus* is considered as threatened species and included in the IUCN red list (Cockcroft et al., 2011). Therefore, the species need to be protected (Bachir Boudjra et al., 2014) for reconstitution of the population.

Due to the market value of *P. mauritanicus* species, its exploitation has been rapidly intensified, leading to an overexploitation of this species (Bachir Boudjra et al., 2014; CGPM, 1985). Indeed, in the past the pink spiny lobster was caught using baited traps, but now this gear has practically disappeared to be replaced almost exclusively by non-selective gears trammel nets (Goñi et al., 2003) and trawl. With the replacement of traps, fishing effort on *P. mauritanicus* has increased contributing a lot in the decline of the exploitable stock (Bensahla et al., 2016). However for example, length structure data for the catches of *P. mauritanicus* are limited as reported by Goñi and Latrouite (2005) particularly along the Mauritanian coasts. Therefore, scientific data and important information are necessary to find solutions for sustainable management and exploitation of the species.

In Mauritania, with the exception of the rare works such as those of Postel (1966), Maigret (1978) and Boitard (1981), no specific studies have been devoted to the biology of this species. Information on growth parameters and the exploitation status of the species in the Mauritanian coasts will be useful to scientists, stakeholders and policy makers in taking measures for sustainable use and protection of the species.

This study is aimed to evaluate the population growth parameters and the stock status of the species fished on Mauritanian coasts. More specifically, it is to: (I) determine demographic growth parameters and their relationship to the dynamics of exploitation, (II) determine parameters of mortality of the species and (III) analyze the level of exploitation that can be used to propose management measures.

MATERIAL AND METHODS

Study area

The Atlantic Ocean is the Western border of Mauritania, with a coastline of 754 km. In the South-West, the border of Senegal with coastline of 813 km long is marked by the Senegal River. The main border (2237 km) separates it from Mali, to the East and to the Southeast. Mauritanian

country is bordered by Algeria (463 km of border) to the Northeast and Western Sahara (1561 km of border) to the North and North-West.

Rainfall is very low and generally does not exceed 100 millimeters per year. However, the fog caused by the current of the Canaries in the Atlantic Ocean brings a certain humidity allowing the development of the lichens and plants that are not very demanding in water. The Sahara Desert occupies almost the entire territory, with the exception of a narrow coastal fringe. This littoral zone is nevertheless called Atlantic coastal desert. In Southern Mauritania, acacia savannah is the predominant ecosystem. Since the 1960s, due to intense and recurring droughts, the Sahara Desert is gradually expanding. These repeated droughts have led Mauritania to become interested in the fishing sector since the 1970s (Marti, 2018).

Sampling techniques

For the collection of spiny lobster data, simple random sampling was used during the creel survey. In addition to the monthly monitoring (February to August 2015) at sea by scientific observers, regularly from March to August 2015, a sampling on boats without observers on board was carried out at the landing either at the port or at the transformation factories during the period of their sorting, packaging and / or packaging in fish ponds. For each individual, the following parameters were measured to the nearest millimeter with a vernier caliper.

The total length (Lt) was measured from the origin of the inter-orbital spine to the end of the telson, the animal being placed on a table,

The length of the cephalothorax (Lc) was taken from the tip of the rostrum to the posterior border of the cephalothorax (Figure 1).

At the same time, all these individuals were also weighed to the nearest gram, their sex noted and the degree of sexual maturity of the females estimated according to the scale of macroscopic maturity proposed by Weinborn (1977) modified by Briones-Fourzan et al. (1997) as represented in Table 1.

Data analysis

The monitoring of the pink lobster fishery involved regular sampling of length frequencies and some biological parameters. The collected data were entered on Excel spreadsheet and the growth parameters were estimated with the FISAT II software (FAO and ICLARM Stocks Assessment Tools).

The stock assessment was conducted using Jones' cohort analysis method based on length frequencies. Exploitation levels were evaluated by the performance-per-recruit model based on demographic structures. Length frequencies, cohort analysis, demographic structures and performance-per-recruit model were performed on FISAT II software (Gayaniilo et al., 2005).

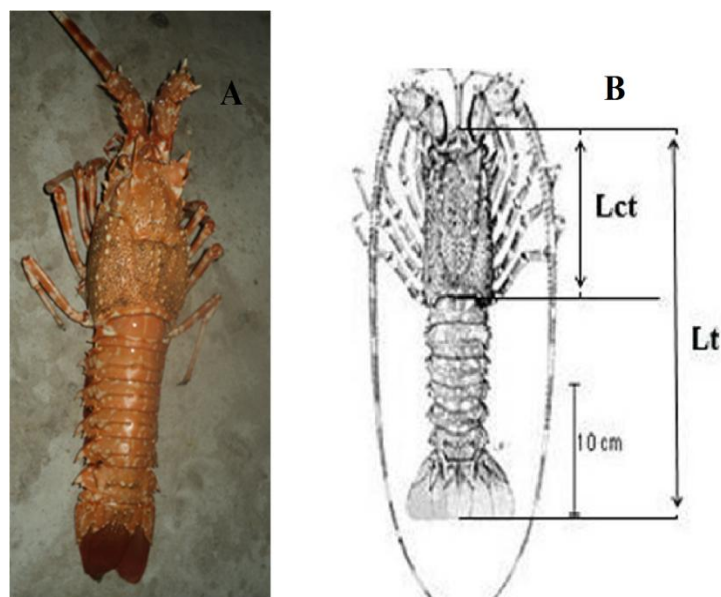


Figure 1: Total length (Lt) and length of the cephalothorax (Lc) measurement. B: image from Bensahla et al. (2016)

Table 1. Macroscopic maturity scale according to Briones-Fourzan et al. (1997)

STAGES	CHARACTERISTICS
I	No spermatophore or external eggs in incubation
II	With spermatophore, without external eggs in incubation
III	With external eggs incubating light orange
IV	With external eggs incubating dark orange.
V	Occluded external eggs with coffee color
VI	With leftover spermatophores and eggs or fine hairs where eggs adhere

Analysis of length frequency of *P. mauritanicus*

Lengths of *P. mauritanicus* were grouped into 5 mm gap class considering separately male and female. For each length class, a center is calculated and the corresponding number of individuals assigned. In order to verify the absence of variability between males and females, was performed as a comparison test of averages. This test, based on the reduced gap according to Bedda and Boufersaoui (2009), was expressed by the relation of Schwartz (1993) according to Equation 1.

$$\varepsilon = \frac{|mA - mB|}{\sqrt{\frac{SA^2}{nA} + \frac{SB^2}{nB}}} \quad \text{Equation 1}$$

In this equation, *mA*: average length of sample A (females); *nA*: number of sample A; *SA*: variance of the sample A; *mB*: mean length of sample B (males); *nB*: sample length B; *SB*: Variance of the sample B.

If $\varepsilon > 1.96$ the difference is significant at 5%

If $\varepsilon < 1.96$ the difference is not significant at 5%

Sex ratio and statistical analysis of *P. mauritanicus*

The overall sex ratio and sex ratio by length class were determined. The overall sex ratio is the ratio of the number of males and females in a population. According to DIA (1988), if this ratio is expressed as a percentage of males or females, it corresponds respectively of the masculinity rate (Mr) or the femininity rate (Fr) as seen in Equations 2 and 3.

$$Mr = \frac{Nm}{Nt} * 100 \quad \text{Equation 2}$$

$$Fr = \frac{Nf}{Nt} * 100 \quad \text{Equation 3}$$

Where *Nm*: number of males; *Nf*: number of females; *Nt* = *Nm* + *Nf*

According to Garcia and Albaret (1977), the expected result is in general a numerical equality between the sexes and

any differences are considered as apparent deviations from the normal situation.

The determination of the confidence interval or the confidence limits was used to verify the fidelity of the estimate of the sex ratio that is the probable difference between the estimate and the real value. The observation of a percentage p_0 on a sample of n cases can be used to assign to the unknown percentage p , confidence interval at 95% (Schwartz, 1993) which is expressed as follows in Equation 4:

$$p = p_0 \pm t_{n-1} * \sqrt{\frac{p_0 q_0}{n}} \quad \text{Equation 4}$$

In this equation: p_0 = observed percentage of females, q_0 = observed percentage of males, n = total number of males and females, t_{n-1} = the fractiles of the 'law of distribution t' or 'law of Student'.

For a threshold of 95%, and for $n-1$ large, the expression becomes as in Equation 5:

$$p = p_0 \pm 1.96 * \sqrt{\frac{p_0 q_0}{n}} \quad \text{Equation 5}$$

Age and growth of *P. mauritanicus*

Length frequency data were used in this study to determine age by the Bhattacharya method (1967) using the FISAT II software program (Gayanilo et al., 2005). The Bhattacharya method allowed a slicing of the catch histogram in a sum of normal distributions (Doquin, 2004). The objective of this analysis is to obtain for each month a number of cohorts that make up the catches, but also, the average lengths of these cohorts and the standard deviations of the distributions in lengths of these cohorts around the average (Doquin, 2004).

The study of growth was based on determining body length as a function of age (Sparre and Venema, 1996). This relation was obtained by a mathematical model whose parameters were determined by the analysis of the age or length structure. Several models have been used to describe growth. The model used is that of Von Bertalanffy (1938) which remains the most used until now. Due to the existing sexual dimorphism and the observed difference between the mean lengths of males and females, confirmed by the comparison test, the growth study was conducted with separate sexes.

The relative growth (weight-height)

The relation between two measurable quantities of a body can be formulated in equations allowing to compare their growth and to pass from one dimension to another (Harchouche, 2006). The weight-length relationship is used to convert the height of a fish to the theoretical weight or

vice versa. The evolution of the weight (W) of crustaceans as a function of the cephalothoracic length (L_c) results in a power function as following in Equation 6:

$$W = a(L_c)^b \quad \text{Equation 6}$$

W : total weight in grams

L_c : cephalothoracic length in mm

a : ordinate at the origin

By a logarithmic transformation, the linearized equation is in the form as described in Equation 7:

$$\ln W = a + b \ln L_c \quad \text{Equation 7}$$

The nature of allometry is defined by comparing the value of b with the theoretical value of 3 and applying Student's "t" test (for $\alpha = 0.05$). If the value of b is equal to three (3), the growth is called isometric. In the opposite cases, it is a higher allometry if b is greater than 3 or a minor allometric if b is less than 3 (Ricker, 1975).

The applied Student's test is expressed as follows (Bouaziz et al., 1998; Patricio and Cristian, 1999) in Equation 8:

$$t = \frac{b-3}{S_b} (S_b)^2 = \frac{(S_y/S_x)^2 - (b)^2}{N-2} \quad \text{Equation 8}$$

With a d.d.l. = $N - 2$ and $\alpha = 5\%$

Where b = slope calculated by the least square's method;

S_b = standard deviation of the calculated slope;

3 = theoretical slope;

N = number of pairs of values;

S_x = standard deviation of x (L_c);

S_y = standard deviation of y (W); and

d.d.l. = degree of freedom.

If $t < 1.96 \rightarrow$ the difference is not significant

If $t \geq 1.96 \rightarrow$ the difference is significant

The linear growth depending on age

Linear growth is studied using the von Bertalanffy growth equation (1938) which is a descriptive model of the growth depending on the age and taking into account the seasons (Sparre and Venema, 1996) as seen in Equation 9.

$$L(t) = L_{\infty} (1 - e^{-K(t-t_0)}) \quad \text{Equation 9}$$

Where $L(t)$ is the length at age t , L_{∞} is the asymptotic length or the theoretical maximum length, K is the evolution rate of the animal at L_{∞} . $K > 0$ to the age when the length of the fish is theoretically nul ($L(t) = 0$). L_{∞} and K were determined from the analysis of the length frequency distribution using FISAT II 2005 and following the equation of Pauly (1985). According to this equation, $L_{\infty} = L_{\max}/0.95$ and L_{\max} is the length of the largest fish

measured in the sample.

The value of t_0 is obtained from the empirical equation recommended by Pauly (1980) as following Equation 10:

$$L_{10}(-t_0) = -0.3922 - 0.2752 \log_{10} L_{\infty} - 1.038 \log_{10} K \quad \text{Equation 10}$$

Growth weight

There is a typically power relationship between the weight and length. This relationship can be expressed using von Bertalanffy's growth equation, as following in Equation 11:

$$Lc(t) = Lc_{\infty}(1 - e^{-k(t-t_0)}) \quad \text{Equation 11}$$

With the length - weight relationship: $W(t) = a(Lc)^b$

If the asymptotic weight corresponds to $W_{\infty} = a(Lc_{\infty})^b$, $W(t) = W_{\infty} (1 - e^{-k(t-t_0)})^b$, a and b being the relative growth parameters between length and weight.

Study of the exploitation of *P. mauritanicus*

Evaluation of the exploitation kinetics of *P. mauritanicus*

Parameters of mortality such as the natural mortality, the mortality by fishery and the total mortality were estimated. The natural mortality (M) was estimated by application of the formula of Cruz et al. (1981) as described in equation 12:

$$M = -0.0277 - (0.0004 * Lc_{\infty}) + (0.5397 * K) + 0.0119 * T \quad \text{Equation 12}$$

Lc: asymptotic length of cephalothorax,

K: the growth coefficient

T = average temperature of the sea in °C.

Total mortality was estimated from the length-based catch curve using the FiSAT II software (Gayanilo et al., 2005).

Fishing mortality was obtained by Equation 13 (Sparre and Venema, 1996):

$$F = Z - M \quad \text{Equation 13}$$

The exploitation rate (E) was also estimated and defined by Gulland (1971) as in Equation 14:

$$E = F/Z \quad \text{Equation 14}$$

where F is fishing mortality and Z is total mortality

The exploitation status

In this study, the following models were applied: global models and analytical or structural models.

Length-based cohort analysis (Jones, 1984);

The performance-per-recruit model (Beverton and Holt, 1966).

The return-per-recruit models of Beverton and Holt (1966) are predictive models. They can predict future production and biomass at different levels of fishing effort (Sparre and Venema 1996) and thus identify appropriate management measures (Gayanilo et al., 2005).

Analysis of cohorts based on length

Jones' length-based cohort analysis is, in fact, an analysis of pseudo-cohorts because we are not dealing with real cohorts. It is based on a system of constant parameters. This method has been described by Sparre and Venema (1996) and Gayanilo et al. (2005). The steps are summarized as follows:

$$\text{Class interval } i = (L_i, L_{i+1}) \quad \text{Equation 15}$$

$$\text{Relative age } t(L_i) = t_0 - \frac{1}{K} * \ln \left(1 - \frac{L_i}{L_{\infty}} \right) \quad \text{Equation 16}$$

Time it takes a cohort to grow from L_i : Δt_i

$$\Delta t_i = \frac{1}{K} \ln \left[\frac{L_{\infty} - L_i}{L_{\infty} - L_{i+1}} \right] \quad \text{Equation 17}$$

Natural mortality factor:

$$\left[H_i = \frac{L_{\infty} - L_i}{L_{\infty} - L_{i+1}} \right]^{M/2K} \quad \text{Equation 18}$$

Number of survivors:

$$N(L_i) = [N(L_{i+1}) * H_i + C_i] * H_i \quad \text{Equation 19}$$

Exploitation rate:

$$E = F/Z = \frac{C_i}{[N(L_i) - N(L_{i+1})]} \quad \text{Equation 20}$$

Fishing mortality:

$$F = M * (F/Z) / (1 - F/Z) \quad \text{Equation 21}$$

Total mortality:

$$Z = M + F \quad \text{Equation 22}$$

$$\text{Average body weight: } \bar{W}_i = a \left[\frac{(L_i + L_{i+1})}{2} \right]^b \quad \text{Equation 23}$$

where a and b are the parameters of the length - weight
The number of survivors during Δt , the time it takes for a

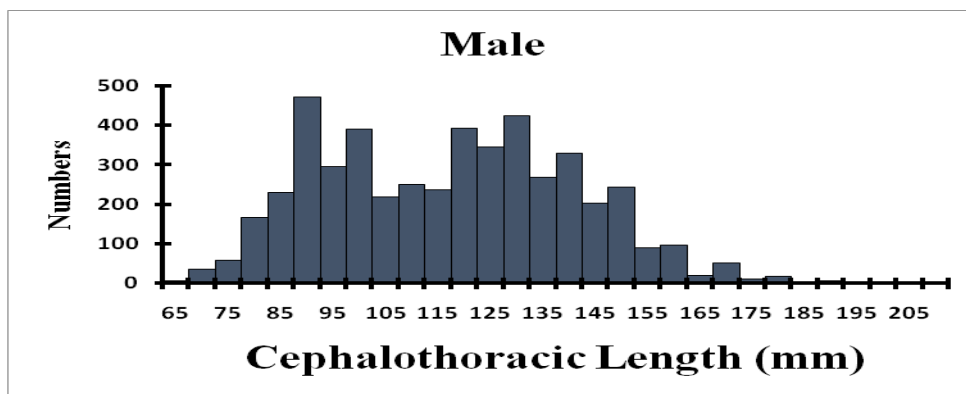


Figure 2: Evolution of the length frequencies of the male rock lobster

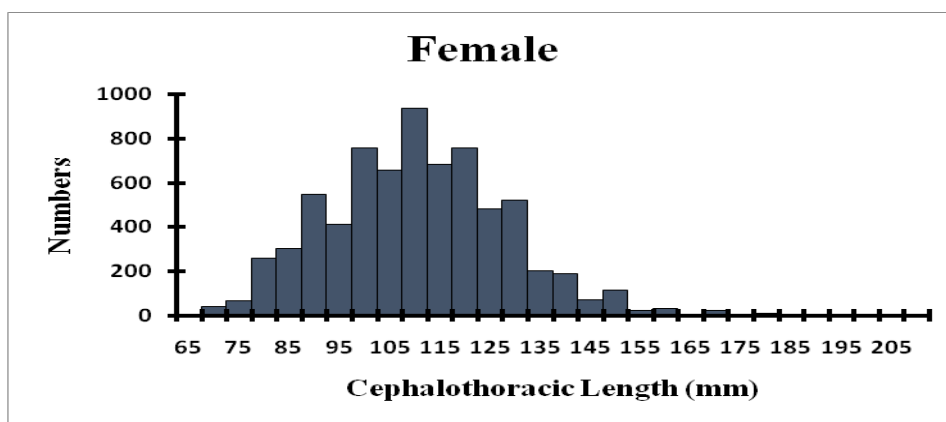


Figure 3: Evolution of the length frequencies of the female pink spiny lobster

cohort to grow from L1 to L2 and the corresponding biomass are of the form:

$$\bar{N}_i * \Delta t_i = \frac{[N(L_i) - N(L_i + 1)]}{Z_i} \quad \text{Equation 24}$$

$$\bar{B}_i * \Delta t_i = \bar{N}_i * \Delta t_i * \bar{W}_i \quad \text{Equation 25}$$

The production (tons) by length class is as $Y_i = C_i * \bar{W}_i$ Equation 26

All these analyzes were carried out using the FISAT II software.

Rookie Performance Model

The model of Beverton and Holt (1966) based on Knife Blade Selection was used to determine evolution of biomass in response to changes in exploitation rates. The relative production model per recruit or relative output per recruit is noted as Y'/R .

It belongs to the category of models based on length. Its mathematical formulation is as follows:

$$\frac{Y'}{R} = EU^{M/K} \left\{ 1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} + \frac{U^3}{(1+3m)} \right\} \quad \text{Equation 27}$$

$$U = 1 - (L_c/L_\infty) \quad \text{Equation 28}$$

$$m = (1-E)/(M/K) = (K/Z) \quad \text{Equation 29}$$

where $E=F/Z$

The relative biomass per recruit (B'/R) is estimated by the following relationship:

$$B'/R = (Y'/R)/F \quad \text{Equation 30}$$

All these analyzes were carried out using the FISAT II stock evaluation software and all inputs and outputs are explained in detail in the user manual (Gayanilo et al., 2005).

RESULTS

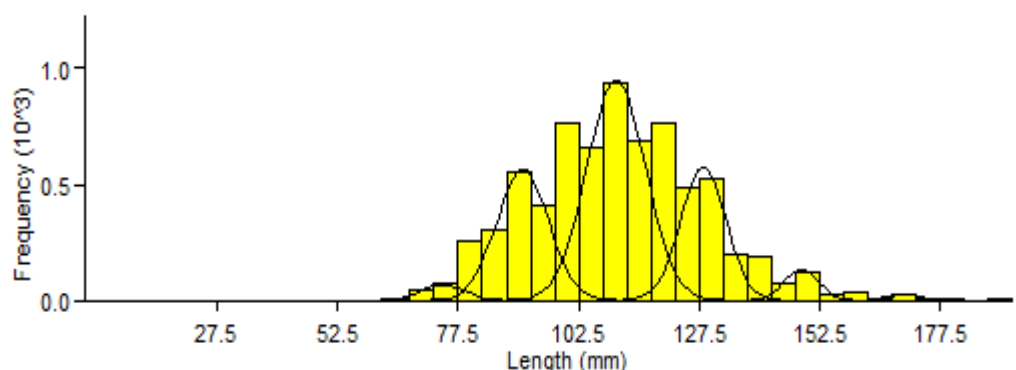
Demographic structures of *P. mauritanicus*

Length frequency distribution

Lengths ranged from 65 mm to 210 mm for males and 65 to 190 mm for females (Figures 2 and 3). In the male there were two main modes at 90 mm and 130 mm, while in the female there was a dominant mode at 110 mm.

Table 2. Minimum, maximum and average length of males and females of the rock lobster with comparison test

	Females	Males
Lc min	63	65
Lc max	190	210
Lc average	111	117
Variance	320.95	567.54
ε	16.24	

**Figure 4:** Decomposition of length frequencies of female lobsters

Important portion of collected individuals of female was characterized by Lc ranged from 90 mm to 130 mm. However for males, the major individuals were characterized by Lc ranged from 90 mm to 150 mm in the collected stock.

Sex-ratio in the sampled stock

In the total sample of 12,008 individuals, 7,144 females and 4,864 males were identified. Therefore, the masculinity rate (Mr) and the feminity rate (Fr) are respectively 41% ($\pm 20\%$) and 59% ($\pm 29\%$) as the confidence interval of 95% calculated for males and females are respectively 20% and 29%.

Length averages

By using t-test for comparison, the analysis of mean lengths of males (117 mm) and females (111 mm) showed a significant difference between the two sexes. These observations were confirmed by the reduced gap test ($\epsilon = 16.24$) (Table 2).

Age and growth

The treatment of the annual length frequency distribution of the pink lobster from the Mauritanian coasts by the method of Bhattacharya (1967), gave 6 age-groups for females (Table 2 and Figure 4) and 7 for males (Table 3 and Figure 5).

Relative growth

The biometric relationship between cephalothoracic length (Lc) and total length (Lt) for males, females, and both sexes is reported in Table 4. Regardless of sex, these relationships show a minor allometry ($b < 3$). Thus, the total length (Lt) grows faster than the cephalothoracic length.

The results of the relationship between weight (Wt) and cephalothoracic length (Lc) are given in Table 5 and illustrated in Figures 6, 7 and 8. The result of the test shows a significant difference between the theoretical value of b and the calculated value. The allometry is therefore of the minor type ($b < 3$).

Linear growth and growth weight

The parameters have been estimated by different methods that are: Powell-Wetherall, Elefan I and Pauly. The values obtained by these methods show that Elefan I gave a better estimate (Table 6) with $L_{\infty} = 199.5$ mm, $k = 0.22$ for females, $L_{\infty} = 220.5$ mm, $k = 0.32$ for males, and $L_{\infty} = 220.5$ mm, $k = 0.21$ for both sexes. Therefore, values of parameters obtained from Elefan I were used to plot the growth curve.

For t_0 estimated at -0.54 for females, at -0.46 for males and at -0.61 for both sexes, the Von Bertalanffy equation is of the form as in Equations 31, 32 and 33:

$$Lc(t) = 199.5(1 - e^{-0.22(t+0.54)}) \text{ for females Equation 31}$$

Table 3. Mean age-length key values of female and male spiny lobsters

Sexes	Groups	Means	S.D.	Population	S.I.
Female	1	74.42	4.39	149.39	n.a
	2	90.89	5.31	1513.56	2.17
	3	110.26	5.99	2872.80	2.17
	4	128.34	4.69	1343.00	2.13
	5	148.66	3.48	229.01	2.18
	6	169.71	2.94	38.96	2.19
Male	1	74.35	4.23	118.67	n.a
	2	90.56	4.58	1119.73	2.19
	3	111.14	10.55	1344.62	2.11
	4	130.13	5.42	1034.97	2.05
	5	148.49	4.5	597.62	2.12
	6	169.29	3.04	83.71	2.17
	7	189.4	2.94	9.47	2.16

S.I.: separation index which must be greater than 2 (Gayaniilo et al, 2005)

S.D.: Standard Deviation

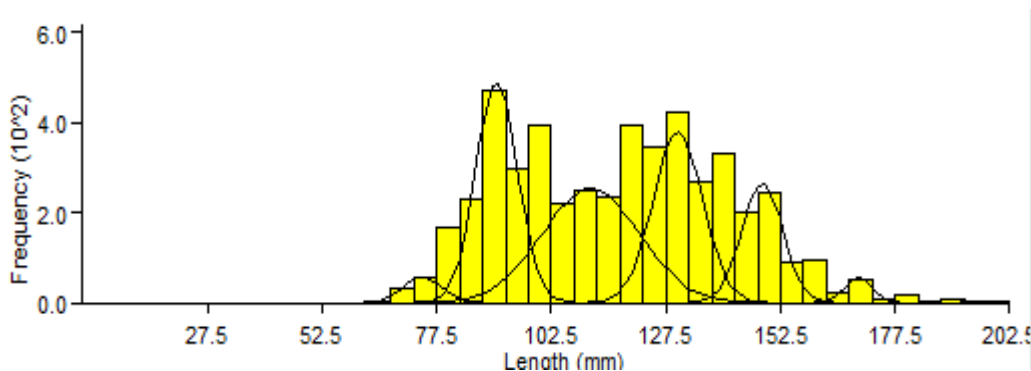


Figure 5: Decomposition of length frequencies distribution of male lobsters

Table 4. Biometric relationship of the pink lobster

Sexes	Relationship	r ²	N
Males	Lc = 0.4149*Lt ^{-0.9905}	0.977	294
Females	Lc = 0.3841*Lt ^{-0.4965}	0.952	516
Total	Lc = 0.4038*Lt ^{-0.9273}	0.955	810

Table 5. Parameters of the height-weight relationship

Sexes	N	a	b	Relation	r ²	t _{cal} α = 5%
Male	958	0.00159	2.7449	W = 0.0016Lc ^{2.7449}	0.9708	16.697
Female	1652	0.00188	2.71836	W = 0.0019Lc ^{2.7184}	0.9383	19.296
Both Sexes	2610	0.00192	2.7109	W = 0.0019Lc ^{2.7109}	0.9523	24.345

$Lc(t) = 220.5(1 - e^{-0.32(t+0.46)})$ for males Equation 32

$Lc(t) = 220.5(1 - e^{-0.21(t+0.61)})$ for both sexes Equation 33

The growth curves were then plotted from these equations (Figure 9). Analysis of curves shows that at t = 0, males

were larger than females. Initially, the growth curve of the lobster population shows an age of both sexes (male and female) up to 4 years. Beyond it gradually moves away to be confused with that of males for Lc close to Lc∞.

The growth weight was obtained from the combination of the weight-length relationship and the growth equation of Von Bertalanffy as following in Equations 34 to 36:

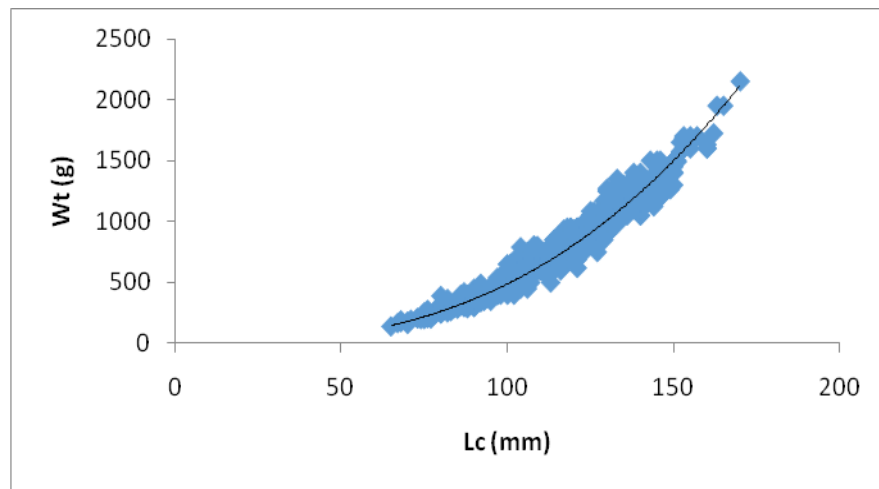


Figure 6: Weight-length relationship of the males of the lobster

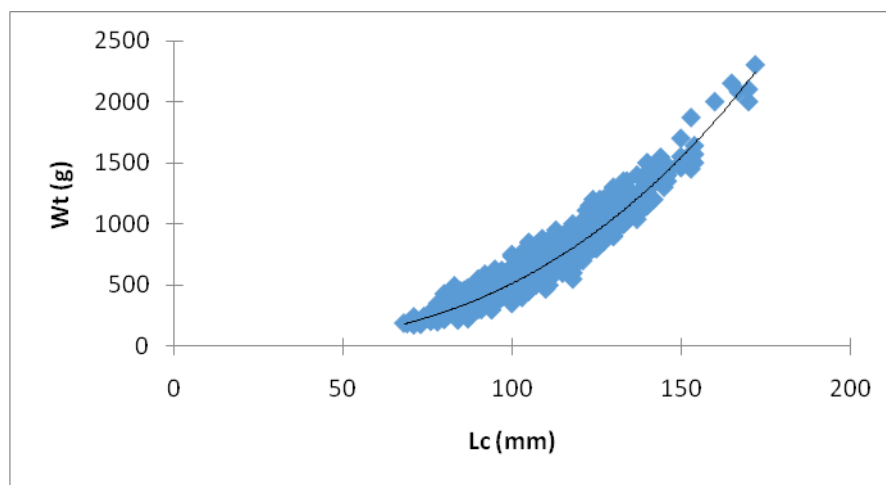


Figure 7: Weight-length relationship of the females of the lobster

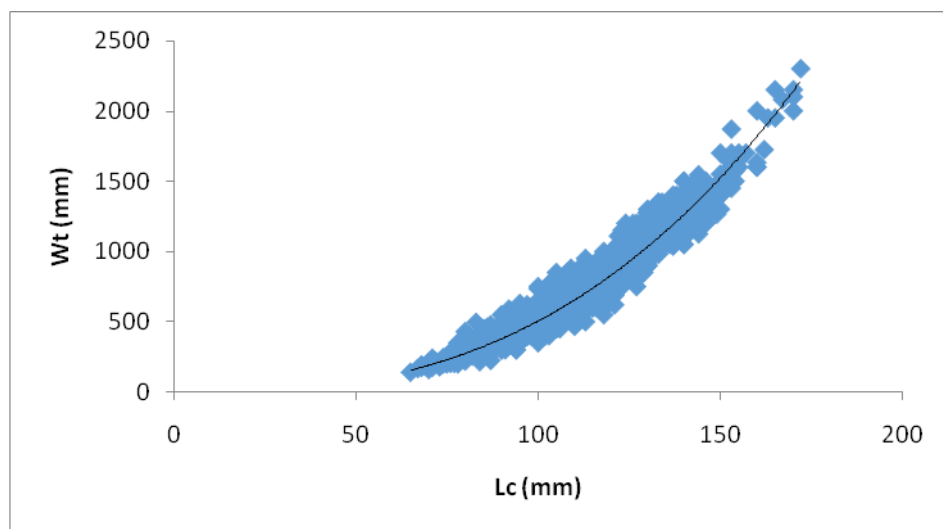


Figure 8: Weight-length relationship of both sexes of the lobster

Table 6. Parameters for equation of Von Bertalanffy

Methods	Females		Males		Females + Males	
	Lc∞ (mm)	K(an ⁻¹)	Lc∞ (mm)	K (an ⁻¹)	Lc∞ (mm)	K ((an ⁻¹))
Powell-Wetherall	191.16	-	227.21	-	222.54	-
Elefan I	199.50	0.22	220.50	0.32	220.50	0.21
Pauly	202.10	-	223.15	-	223.15	-
t ₀	-0.54		-0.46		-0.61	

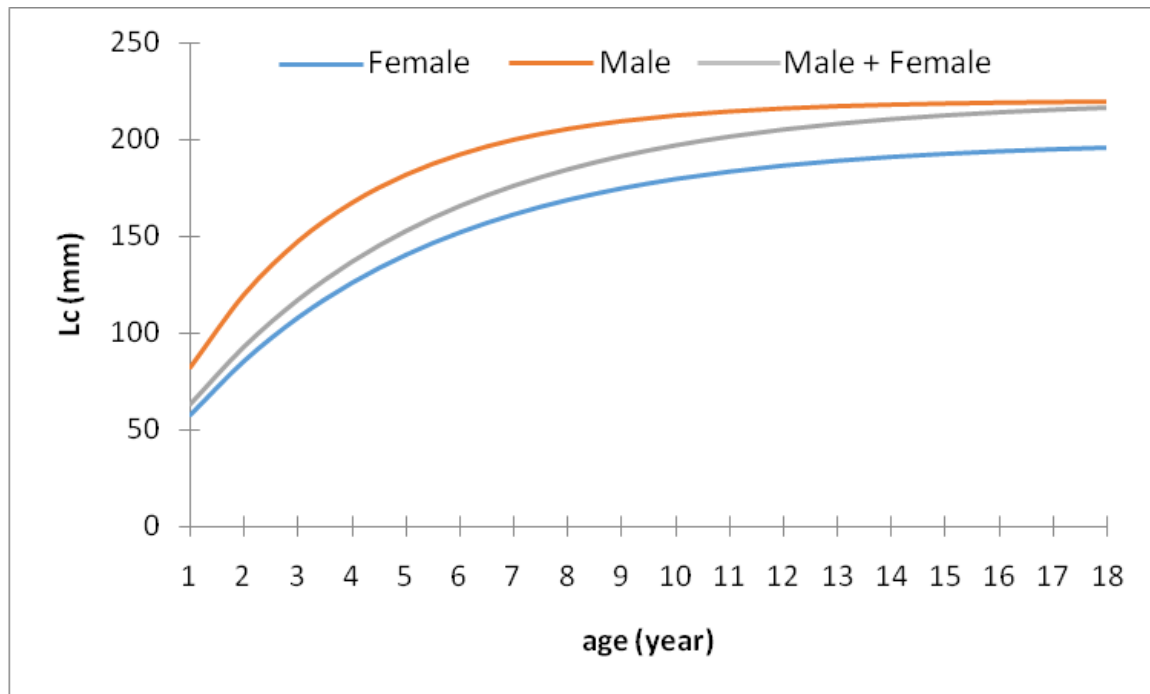


Figure 9: Growth of male and female depicted by Von Bertalanffy growth function

Table 7. Monthly catches of pink lobster

Month	February	March	April	May	June	July	August	Total
Catches (tons)	21	76	92	96	89	53	68	495

$W(t) = 3062.36(1 - e^{-0.22(t+0.54)})$ for females Equation 34

$W(t) = 4198.48(1 - e^{-0.32(t+0.46)})$ for males Equation 35

$W(t) = 4098.85(1 - e^{-0.21(t+0.61)})$ for both sexes Equation 36

Exploitation of *P. mauritanicus*

The pink lobster fishery is carried out by vessels using gillnets. In total about twenty coastal and industrial vessels exploit the pink lobster fishery. These vessels have a length varying between 14 and 27 m and a power ranging from 187 to 800 Cv. The fishing gear used by these vessels is

a gillnet consisting of an average of 70 layers of 25 m to 40 m long and 2 m of fall in series.

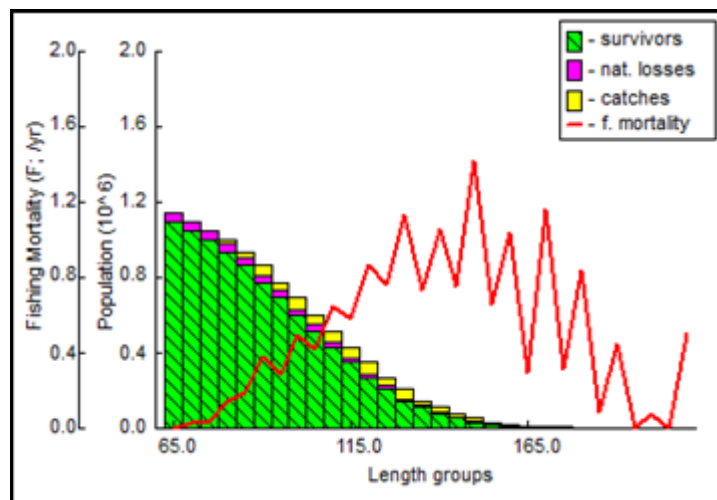
Evaluation of exploitation kinetics

During the period from February to August 2015, catches reached 495 tons (Table 7). The peak of production was reached in May, followed by a fall until July. From July to August, increasing of catches was observed (53 to 68 tons).

The natural mortality M, total mortality Z, mortality by fishing F, as well as the exploitation rate E reported in Table 8 were estimated using FiSAT II. The total mortality (Z) for females, males, and both sexes per year was respectively 1.31, 1.79 and 1.35. The mortality of males was more than that of females. Fishing is the main cause of the annual

Table 8. Exploitation parameters of the spiny lobster

Sexes	M (year ⁻¹)	Z (year ⁻¹)	F (year ⁻¹)	E
Female	0.27	1.31	1.04	0.79
Male	0.32	1.79	1.47	0.82
Both sexes	0.26	1.35	1.09	0.80

**Figure 10:** One cohort analysis based on length

mortality of the species ($F = 1.04$ to 1.47 a year).

Exploitation rate values by sex also showed that males were more vulnerable than females. This rate is $E = 0.82$ for males, 0.79 for females and 0.80 for sexes combined. These values reflect a high fishing effort because they are higher than the equilibrium situation ($E = 0.5$).

Exploitation status

Results from Jones' cohort analysis based on the length (Figure 10) show that recruitment is estimated at 1143837.25 . Small individuals ($L_c < 90$ mm) are not significantly affected by fishing mortality. Fishing mortality (F) increases with increasing length to a maximum of 1.4138year^{-1} , affecting individuals of length $L_c = 150$ mm.

Production and Relative Biomass by Recruit using the Knife Blade Selection Method showed that the current relative yield is 0.0559g for a fishing mortality of 1.09 . The current relative biomass is 0.0513g for the same fishing mortality value. Figure 11 shows fishing mortality by length and sex. For smaller lengths (less than $L_c = 100$ mm), fishing mortality was slightly higher in males. Beyond 100 mm, it affected more females and become superior again in the males. This reinforces the results about the exploitation rate being higher for males.

The value of E_{max} , exploitation that produces a maximum yield is 0.625 , the value of E_{10} , which results in a production increase of 10% compared to $E = 0$ is 0.502 and that of E_{50} , the value under which the stock is at 50% of

its untapped biomass, is equal to 0.347 (Figure 12).

The relative biomass curve decreases progressively according to the exploitation rate. The relative production increased gradually with the increase of the exploitation rate up to a maximum value, then decreases. The value of relative production per recruit corresponding to the current exploitation rate $E = 0.80$ is located on the downward part of the curve. This indicates a situation of overexploitation of the resource.

DISCUSSION

The demographic structure of *P. mauritanicus*

The male *P. mauritanicus* collected along the coastal rivers of Mauritania had the lengths ranged from 65 mm to 210 mm while for female; they ranged from 65 to 190 mm. The most collected individuals of male were characterized by L_c ranged from 90 mm to 150 mm while the most harvested individuals of females were characterized by L_c between 90 mm and 130 mm. The homogeneity test based on the calculation of the reduced difference (Schwartz, 1993) showed a $\varepsilon = 16.24$. That would therefore mean the fact that the males were on average larger than the females and the two length structures were different. The collected individuals were found to be mostly adults as the average length of harvested species was about 117 mm for males and 111 mm for females. In the stock, six groups and seven

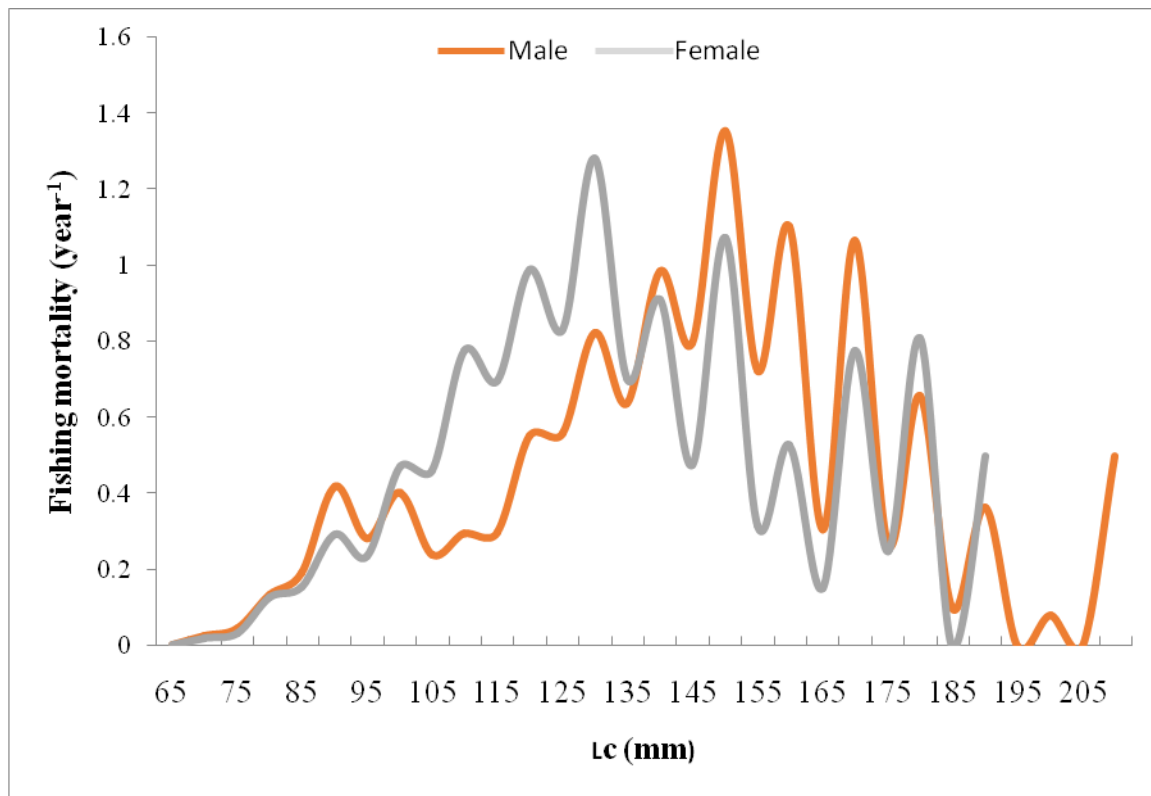


Figure 11: Fishing mortality by length class and by sex

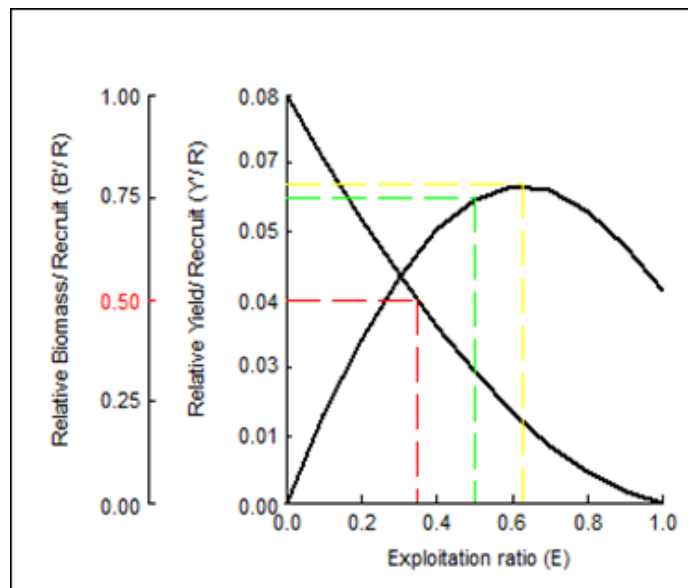


Figure 12: Production per recruit curves and relative biomass as analysed by the knife method.

groups were sorted respectively for females and males in the stock. According to Goñi and Latrouite (2005), Vincent-Cruz (1966) divided the lengths comprised between 27 cm and 49 cm into 8 groups for both sexes in Mauritania. The

high number of sorted groups for males as well as for females indicates that the structure of the species going from the smallest individuals (65 mm) to the largest (210 mm) is strongly heterogeneous in the stock. Considering

the lengths in the structure of the species, they seem to remain almost the same since 1972 as according to Goñi and Latrouite (2005), the landings of *P. mauritanicus* carried in 1972-1974 indicated maximum lengths of 217 mm for males and 195 mm for females in Mauritania. These results are in accordance with the findings in this study where indicated in the stock, maximum lengths of 210 mm for males and 190 mm for females. Furthermore, they found that $L_{\infty} = 202$ mm and $k = 0.169$ very close to the results of the present study where $L_{\infty} = 199.5$ mm, $k = 0.22$ for female.

However, in the stock, an imbalance is observed regarding female-male ratio. Indeed, *P. mauritanicus* captured along the Mauritanian coasts, the number of females was high than that of males with respectively $M_r = 41\%$ and $F_r = 59\%$. The male-female ratio in the catches obtained after macroscopic observation of gonads and sorting of males and females is a useful data, either to better know the demographic structure of a population, or to estimate the fecundity of the stocks (Camarena, 1986). It is generally known that in a population, the sex ratio should be 1:1. There are several other factors such as temperature, water velocity, and vulnerability of females to their predators, migratory phase and other ecological hazards, which probably change the sex composition in streams or rivers (Domínguez-Petit et al., 2017). According to the results of this study, the females were significantly higher in number than males in the Madeiran Sardinella stock. The causes for skewed sex ratios have been suggested to stem from differences in length and age linked natural mortality between the sexes (Jakobsen and Ajiad, 1999), differential predation (Britton and Moser, 1982). Length selective and unequal removal of the sexes by fishing (Shepherd et al., 2010) seems to be the main reason of the lower number of male in the stock as adult females were found to be higher in length (more sensible to be removed) than females.

Species growth and its biometric relationships

The relationship between L_c and L_t and also W_t showed that the allometry was of the minor type ($b < 3$) in the stock of *P. mauritanicus*. The minor allometry type of the relationship between L_c and L_t is consistent with the results of Maigret (1978) who obtained for the male and the female the following relations:

$$L_t = 2.15L_c + 24.1 \text{ and } L_c = 0.4651L_t - 11.21 \text{ for male}$$

$$L_t = 2.33L_c + 15.2 \text{ and } L_c = 0.4292L_t - 6.52 \text{ for female}$$

Boitard (1981) also found that populations of *P. mauritanicus* off northeast Africa were characterized by $W = 0.001826L_c^{2.756}$ for males and $W = 0.002156L_c^{2.729}$ for females. In this study, approximately the same results were found with $W = 0.0016L_c^{2.7449}$ for males and $W = 0.0019L_c^{2.7184}$ for females (Table 4). Variations in growth parameters can be attributed to the combination of one or more factors (Bensahla et al., 2016) such as difference in the number of specimen examined, area/season effect, differences in the observed length ranges of the specimen caught, temperature, food (quantity, quality and size). The

height and weight of a species are strongly sensitive to factors such as the sampling period, the sex and the maturity level of this species (Fréon, 1988). These two parameters were positively correlated ($r = 0.95$) for both sexes in the collected stock during this study.

From the equations of Von Bertalanffy (1983), the growth curves showed that at the L_c (111 mm or 117 mm), the age of recorded individuals was up to 4 years. If the major individuals observed during *P. mauritanicus* caught was characterized by L_c between 90 and 150 mm, the age of the important portion of collected individuals both sexes is between 2 and 4 years. Low number of captured individuals was found to be more than 4 years old. However, the curves show that in the stock, some individuals of about 18 years old were recorded (figure 7). Maigret (1978) estimated that *P. mauritanicus* could live at least 21 years.

Exploitation and sustainable use of the species

Exploited by vessels using gillnets, the pink lobster catches vary with month. During this study, for a total 495 tons harvested from February to August 2015, the high amount was caught in May (96 tons). This variation on exploitation status can be explained by the seasonal factors and the reproduction periods of the species. According to Goñi and Latrouite (2005), *P. mauritanicus* reproduces in late summer and fall. Nevertheless, fishing is the main cause of mortality of the species in Mauritanian coasts. For a total mortality (Z), of 1.31 for females, 1.79 for males, and 1.35 for both per year, the mortality by fishing was respectively 1.04, 1.47 and 1.09 per year corresponding to 80-82 % of the total mortality. Fishing mortality (F) was observed to increase with increasing fish size and can reach a maximum of 1.4138year^{-1} . Consequently, fishing effort strongly affects the reproduction capacity and thereby leading to a decline of the population. Indeed, as shown in figure 9, the value of relative production per recruit corresponding to the current exploitation rate $E = 0.80$ is located on the downward part of the curve, indicating a situation of overexploitation of the species resource in the coasts of Mauritania.

During exploitation of *P. mauritanicus*, males were found to be more vulnerable to fishing net than females. This situation was demonstrated by the exploitation rate $E = 0.82$ for males and 0.79 for females. As stated earlier, the vulnerability of males is due to the fact that males were larger than females.

Conclusion

In the Mauritanian coasts, population of spiny lobster *P. mauritanicus* is found to be overexploited conducting its decline. Even though this study was conducted from February to August and did not consider the period from September to January, evaluation of growth patterns and exploitation status of the species during the study period was used to determine population structure and the effect

of exploitation effort on the stock of *P. mauritanicus*. Treatment and analysis of the length frequency distribution yielded growth parameters and revealed a mean difference in length between males and females. Furthermore, Relative Recruit Yield (Y'/R) analysis has informed us of the evolution of biomass in response to changes in exploitation rates, and situates the current exploitation of the stock in a level of overexploitation of growth. Thus, if the results confirm an overexploitation of *P. mauritanicus* stock, males were mostly caught, collected and vulnerable to fishing net than females as at equal age, males are taller than females. Growth pattern showed allometric relationship which is characterized to be of the minor type. The weight is then found to increase less rapidly than length.

Consequently, an effort to reduce the number of vessels and regular monitoring of this fishery by the boarding of scientific observers aboard these vessels is necessary in order to know the actual effort deployed by these vessels in addition to arrangements recommended by the fisheries regulations. In addition, it would be advisable to adjust the biological shutdown period to the entire maximum reproduction period for this species that is included as threatened species in IUCN red list since 2011.

Perspective studies on the biology of this species notably the fertility, the length of first sexual maturity and the moult will give further usable data and scientific information for sustainable management of the species.

Conflict of interests

The authors declare that they have no conflicting interests

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