



RESEARCH ARTICLE

REPRODUCTIVE BIOLOGY IN GREEN SPINY LOBSTER, *PANULIRUS REGIUS* (DE BRITO CAPELLO 1864), FROM THE PETITE CÔTE OF SENEGAL, WEST AFRICA

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Abstract

Green spiny lobster is one of the highest economically valued fisheries resources in Senegal. However, knowledge on this species are relatively old and insufficient. To realize this study on reproductive biology of *Panulirus regius*, sampling has been carried out between April and September 2017 from small-scale fisheries landed catches at the Petite Côte, Senegal. The length at first sexual maturity computed from the body allometric relationship according to the cephalothorax length (CL) was 67.95 mm in females and 67.51 mm in males. The CL at which 50% of the females were mature during the breeding season (CL_{50}) was 94.50 mm. Individual fecundity was between 229,860 and 638,775 eggs depending on CL of individuals. In the catches surveyed, 64% of landed individuals had a total length (TL) less than 200 mm, which is the minimum landing length in accordance with the Senegalese fisheries law. This result indicates the difficulties to apply management measures relative to this fishery, which could compromise its sustainability in Senegalese' Petite Côte.

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Introduction:-

The proportion of overexploited fish stocks through the world has increased from 10% in 1974 to 33.1% in 2015 (FAO, 2018), and the most impacted stocks are the demersal species. The fisheries resources exploitation is one of the most important socio-economic sectors (Allison et al., 2009; Ba et al., 2016). Among the exploited resources throughout the world, the spiny lobster is one of the most economically valuable fisheries (DPM, 2016; Pereira and Josupeit, 2017).

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Almost all the world demand for lobster is provided by fishing with 80,000 t per year (Latruite and Lazure, 2005). The increase over the years of this demand as well as the fishing pressure on some stocks could compromise the bio-ecological balance and the sustainability of this fishery resource. This risk would be higher for stocks in areas where the regulations on this fishery and/or its application are flawed.

On the Senegal-Mauritanian coasts, two species of spiny lobster have been exploited since a long time (Chevalier, 1957): pink spiny lobster, *Palinurus mauritanicus* (Gruvel 1911) and green spiny lobster, *Panulirus regius* (De Brito Capello 1864). In the Senegalese exclusive economic zone (EEZ), the green spiny lobster seems to register more landings and to generate much higher socio-economic activity than that of the pink spiny lobster (Postel, 1965; Clotilde-Ba et al., 1997).

Several studies on the bio-ecology and exploitation of green spiny lobster have been carried out on the western Atlantic coasts, in the intertropical African zone (Chevalier, 1957; Postel, 1961, 1965; Marchal and Barro, 1964; Crosnier, 1971; Diop and Kojemiakin, 1991; Clotilde-Ba et al., 1997, 2014; Freitas et al., 2007; Dia et al., 2015). Most of these studies are nevertheless relatively old. Indeed, Diop (1996) highlights the difficulty of comparing biometric data within a single species at significantly different periods and geographic areas. According to this author, this difficulty could be related to various factors. Firstly, the climatic, oceanographic and geophysical variations could imply significant ecosystem differences. Furthermore, anthropogenic factors such as the methods and regime of exploitation applied on the resource can significantly have different effects on stocks according to the ecosystems. Thereby, these factors could have repercussions on the population's dynamics of green spiny lobster as well as on the bio-ecology of this species (diet, growth, reproduction).

Those considerations made important to update knowledge on biometrics and biology of the green spiny lobster especially in the Senegalese coasts. The present study uses commercial fishery data in the aim to study the morphometric characters, sexual maturity and fecundity of green spiny lobster in Senegalese Petite Côte (Fig 1). The interest given to the Petite Côte is justified by the relatively predominant activity of the lobster fishery in this central portion of the Senegalese coasts (Postel, 1966; Fall, 2009). Indeed, Postel (1966) estimated that 75% of spiny lobster landings were made on the Petite Côte against 72% in 2014 in the same area (Thiao and Ngom-Sow, 2015).

The results of this study could be useful in establishing management plan for this fishery in Senegalese Petite Côte.

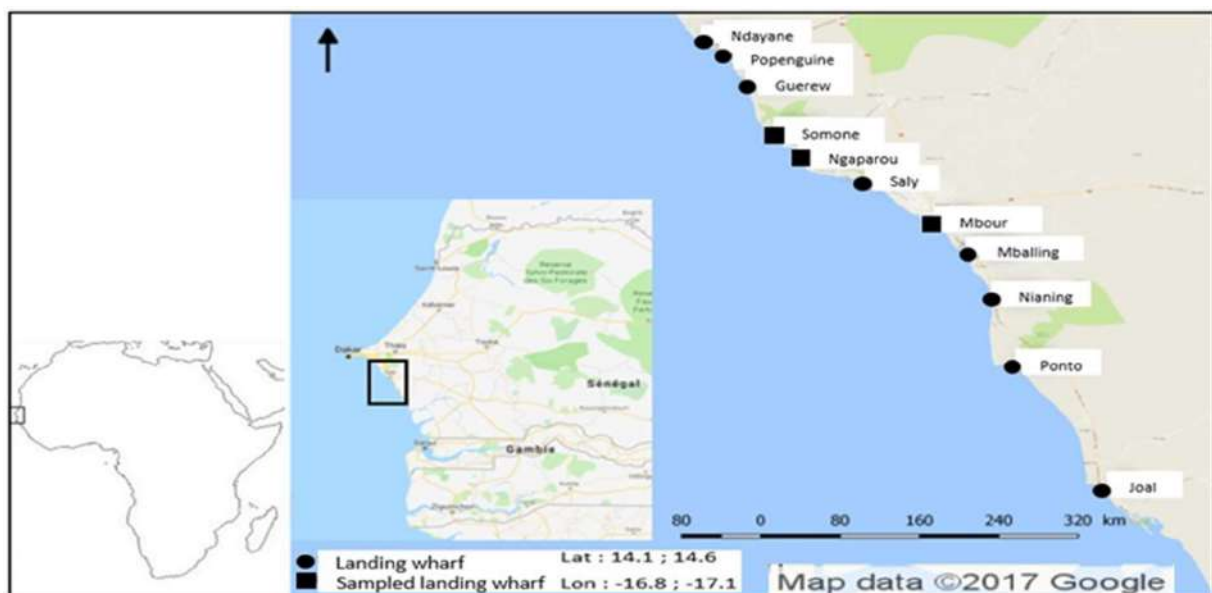


Figure 1:-Geographic location of the study area and the sampled locations in black square

Materiel And Methods:-

Presentation of the study area:

The Senegalese coasts extend from north to south on 700 km, with a marine area of 198,000 km². The Petite Côte, localized from Hann in the region of Dakar to the tip of Sangomar in the region of Fatick, represents the central part

of the Senegalese coastline. It is mostly sandy, with a presence of rocky coasts (CSE, 2005). In the Petite Côte, two marine seasons separated by two transition periods (cooling and warming) of the waters are observed (Rossignol, 1973; FAO, 1979):

Cold season (from December to May) with cold Canarian waters, temperatures $< 24\text{ }^{\circ}\text{C}$ and salinity $> 35\text{‰}$; Warming period (from May to June) with the appearance of early onset of warm tropical waters with temperatures $> 24\text{ }^{\circ}\text{C}$ and salinities $> 35\text{‰}$;

Hot season (from June to November) with tropical waters and warm Guinean waters with temperatures $> 24\text{ }^{\circ}\text{C}$ and salinity $< 35\text{‰}$;

Cooling period (November and December) corresponding to the beginning of cold Canarian waters characterized by temperatures $< 24\text{ }^{\circ}\text{C}$ and salinities $> 35\text{‰}$.

Biometrics and reproductive biology:

Sampling:

Sampling of the green spiny lobster individuals was carried out in the Petite Côte, from the landings of artisanal commercial fishery. It took place between April and September 2017. The choice of this sampling period is justified by the results of previous studies determining the breeding period of green spiny lobster in the Senegalese coasts between April and August (Clotilde-Ba et al., 1997). Individuals were sampled at 3 landing wharfs: Mbour, Ngaparou and Somone (Fig 1). These localities are among the main landing places for lobster' catches in Petite Côte because they are the main tourist sites in this zone offering more marketing opportunities for the landings of this species. The sampling frequency was daily, and the surveyed individuals were randomly selected. Before proceeding measurements for each individual, a dorsal and ventral picture were taken, the sex is determined and all the observations that seem interesting like the hardness of the cuticle, the state of the pereopods, the aspect of the sternum and the presence or no of eggs or spermatophores were noted (Freitas et al., 2007; Kizhakudan and Patel, 2010).

Biometric measurements:

Length measurements were performed using electronic caliper with 0.01 mm of accuracy. The total length (TL in mm) as well as the mass (M in g) were measured using a plastic tape and an electronic balance with an accuracy of 0.1 g, respectively. However, ovigerous females were excluded from the analysis of the length-mass relationship because the mass of eggs could induce a significant bias (Marchal and Barro, 1964). The following measurements described by Berry (1973) and Freitas et al. (2007) were made:

The cephalothoracic length (CL) which is the reference measure for lobster measurements, is defined as the distance along the dorsal midline on the median axis of the rostrum to the posterior end of the cephalothorax;

The total length (TL) is measured along the dorsal midline from the rostrum to the end of the telson;

The cephalothoracic width (CW) represents the measurement performed on the widest part of the cephalothorax;

The second abdominal segment width (SW) is defined as the minimum distance between the pleural spurs of the second segment of the abdomen;

The meropodite length of the second pereopod (ML_2) and of the third pereopod (ML_3) are the longest segment of the pereopod, located between the ischiopodite and the carpopodite as described by Evans et al. (1995).

The abdominal length (AL) is not measured but deduced from the difference between TL and CL.

The length of 200 mm TL which corresponds to the minimum legal landing length under the Senegalese Fisheries legislation (Anonymous, 1998, 2015), is used as a reference point to assess the degree of application of the legislation of this fishery in Senegal.

Determination of morphometric characters:

The determination of morphometric characters in *P. regius* was essentially oriented towards the analysis of sex-mass relationship. Mass variation was studied as a function of total length (TL) or cephalothoracic length (CL):

$$M = aL^b$$

With a = mass index that depends on the chosen units; b = allometric coefficient or condition factor; L = TL or CL. The result of the coefficient b is interpreted as a higher allometry if $b > 3$; minor allometry if $b < 3$ and isometry if $b = 3$. The higher allometry represents a faster weight growth than the length growth and conversely for the minor allometry.

In addition, the relationship between CL and other variables such as CW, SW, TL, AL, ML₂, ML₃ were studied by sex. These analyzes were used to identify the onset of sexual dimorphism (secondary sexual characteristics), to determine the length at first sexual maturity of individuals.

Temporal and structural dynamics of reproduction:

The methodology used to study reproduction (sexual and maturity stages) is described by Velazquez-Abunader (2005) and Dia et al. (2015). From the sexual maturity scale (Table 1), females in state of decalcification of the sternum were considered as belonging to the stage 2. In fact, this phase is prior to the presence of eggs in incubation. It means that the female is ready for mating (George, 2005; Kizhakudan and Patel, 2010).

Table 1:-Sexual maturity scale in *P. inflatus* proposed by Weinborn (1977), modified by Briones-Fourzán et al. (1981 in Velazquez Abunader, 2005)

Sexual maturity stages	Description
I	Without spermatophores or eggs in incubation
II	With spermatophores, without eggs in incubation
III	With light orange eggs in incubation
IV	With dark orange eggs in incubation
V	With eyed coffee colored eggs
VI	With eyed coffee colored eggs and remaining spermatophores, eggs or fine setae where eggs adhere

Determining the length at first sexual maturity:

Morphological maturity approach:

Significant allometric differences in spiny lobster growth, especially between the cephalothorax, the abdomen and the pereiopods, made it possible to estimate the length at first sexual maturity. The length at first sexual maturity was evaluated by using the allometric differences in spiny lobster growth, especially between the cephalothorax, the abdomen and the pereiopods (George and Morgan, 1979; Jayakody, 1989; Evans et al., 1995; Robertson and Butler, 2003; Lakshmi-Pillai, 2007; Kizhakudan and Patel, 2010; Ikhwanuddin et al., 2014). This work was based on the methodology described by George and Morgan (1979) and used in several studies on determining the length at first sexual maturity in spiny lobster (Jayakody, 1989; Evans et al., 1995; Robertson and Butler, 2003; Lakshmi-Pillai, 2007; Kizhakudan and Patel, 2010; Ikhwanuddin et al., 2014). The length at first sexual maturity was estimated following several steps (Jayakody, 1989; Evans et al., 1995; Robertson and Butler, 2003; Lakshmi-Pillai, 2007; Kizhakudan and Patel, 2010; Ikhwanuddin et al., 2014). The first step consists in plotting on the same graph the respective regressions of AL, SW, ML₂ and ML₃ depending on CL from individuals of each sex. Then, a visual examination of these graphs makes it possible to identify the intersection point of the regression lines for individuals of each sex. From the combined reading of these different graphs are identified the intersection points having the lowest value of CL (lower bound) and that having the highest value (upper bound). The interval delimited by the two bounds is used to separate the distribution into two subgroups for each sex: (i) a subgroup made of individuals with a CL smaller than the lower bound; and (ii) another one with those whose CL is greater than the upper bound. The last step was for individuals of each subgroup by sex to plot on the same graph the regression lines of each of these variables AL, SW, ML₂ and ML₃ according to CL. The intersection point between the two regression lines is considered as the length at first sexual maturity.

Functional maturity approach:

The functional maturity approach has been applied to females. The indicators used are: pleopod length, sternum aspect (hard, decalcified or soft) and presence of spermatophores or incubating eggs (George, 2005; Freitas et al., 2007; Kizhakudan and Patel, 2010). Two indices were estimated: the smallest ovigerous female and the L₅₀ which is defined as the length at which 50% of the females sampled during the reproduction period show breeding activity such as the

presence of spermatophores or eggs (Groeneveld and Melville-Smith, 1994; Velazquez Abunader, 2005; Pérez-González et al., 2009).

Fecundity:

The study of fecundity is based on the methodology described by Freitas et al. (2007) and Velazquez-Abunader (2005). Ovigerous sampled and dissected in the laboratory allowed to study the fertility of individuals by collecting eggs on pleopodal setae. After dissection, the eggs are fixed in 40% diluted formalin solution in a tightly closed container and stored in ambient temperature. Then, they are rinsed four (04) times with distilled water using a 100 µm sieve and two beakers. Then, the egg mass was wrapped in aluminum foil and placed in an oven at 40 °C during 72 h. After this step and just before counting, the egg mass is placed in a desiccator with Sillicagel to keep it dry and weighed with a high precision electronic scale (10⁻⁴ g). Egg counting is performed by taking a sub-sample of 0.01 g counted integrally, using an electronic microscope (x 40) and a counting cell. For each ovigerous female used to study the fecundity, two sub-samples are counted, and the average number of eggs is calculated. The average number of eggs counted is then extrapolated to the total dry mass of the eggs to estimate the total amount of eggs by female.

Weighing and counting results were used to compute several indices such as Dry Egg Mass (DEM), Relative Egg Mass (REM), Absolute Fecundity or Individual Fecundity (AF) and Relative Fecundity (RF). These indices are calculated according to the formulas used by de Freitas et al. (2007) and Velazquez Abunader (2005) as following:

$$REM = \frac{\sum_{i=1}^k m_k}{\sum_{i=1}^k n_k} * 10^5$$

With m = subsample mass (portion removed from eggs); n = number of eggs in each subsample; k = number of subsamples.

$$AF = \frac{M * N}{m}$$

M = dry mass of the eggs; N = average number of eggs in subsamples; m = average mass of subsamples.

$$RF = \frac{AF}{m_f}$$

m_f = ovigerous female mass.

Statistical analysis:

Average length and weight were compared between males and females, using the Student's test. The application of this test was preceded by the Shapiro test to verify the normality of length and weight distributions. The covariance analysis (ANCOVA) was used to test the slopes of the regression lines for each of the variables CW, SW, TL, AL, ML₂ and ML₃ according to CL and by sex.

The Spearman correlation test was used to test the correlation degree of each of these relationships. In the case where the slopes were found to be significantly different, the intersection point between both regressions was projected on the CL axis. The corresponding value is considered as the length at first sexual maturity. In the case where the test was not significant, the result of the projection on the CL axis is used as an indication of the length at first sexual maturity. Statistical analyses were performed using the “stats”, “Hmisc” R packages (McDonald, 2009; Harrell Jr, 2017) in RStudio 1.1.463 (Team, 2015), with a significance level of α < 0.05.

Results:-

Sample and morphometric characters of green spiny lobster:

Sample:

Sampling allowed recording 767 individuals including 358 males and 409 females (Table 2). The lowest total numbers of individuals was recorded in April and September. For the females, the relative proportions decreased in August and September. Males mass varied between 48.6 and 1811.3 g with an average of 264.9 ± 251.8 g. Females mass varied between 65.8 and 2111 g with an average of 342.1 ± 241.3 g. Average mass by sex were significantly different (Student's t-test: p < 0.05).

Table 2:-Sample distribution by sex from April to September 2017

	April	May	June	July	August	September	Total
Males	8	62	73	80	83	52	358
Females	12	94	97	87	73	46	409
Total	20	156	170	167	156	98	767

Length-mass relationship and condition factor (b):

The length-mass relationship of green spiny lobster estimated in this study is compared to those determined in the Mauritanian and Ivorian coasts (Table 3). The mass was strongly correlated with length. For both sexes, referring to both CL and TL, length and mass were positively correlated. Depending on the CL, the growth had a lower allometry for both males (b = 2.60) compared to females (b = 2.89). In contrast, based on TL, male individuals had almost isometric growth (b = 2.99) while female individuals had a minor allometry (b = 2.89). For the same TL, male individuals appeared heavier than female individuals with condition coefficients of 2.99 and 2.89, respectively. However, for the same CL, female individuals appeared heavier (b = 2.89) than male individuals (b = 2.60).

Table 3:-Length-mass relationship parameters in *P. regius* from different studies in West Africa coast (CL = cephalothoracic length, TL = total length, M = mass)

Country	Parameters		References
	Males	Females	
Côte d'Ivoire	$M = 3.74 * TL^{3.20}$	$M = 4.22 * TL^{2.84}$	Marchal & Barro (1964)
Mauritania	$M = 3 * TL^{3.17}$	$M = 3.15 * TL^{2.82}$	(Maigret, 1974 in Diop & Kojemiakine, 1991)
Mauritania	$M = 10.10^{-4} * TL^{2.92}$	$M = 65.10^{-4} * TL^{2.64}$	Chavance et Girardin (1991)
Mauritania	$M = 1.247 * CL^{2.66}$	$M = 1,1375 * CL^{2.74}$	Dia et al. (2015)
Senegal	$M = 4.10^{-5} * TL^{2.99}$ ($r^2 = 0.9765$) $M = 0.0043 * CL^{2.60}$ ($r^2 = 0.9348$)	$M = 6.10^{-5} * TL^{2.89}$ ($r^2 = 0.9827$) $M = 0.0013 * CL^{2.89}$ ($r^2 = 0.9811$)	This study

Length distributions:

The modal length class (TL) was 55-59 mm for males and 65-69 mm for females (Fig 2). In total, 64% of landed and sampled individuals had less than 200 mm of TL. By sex, 74% of males and 55% of females had less than 200 mm length TL. The average lengths were 185 ± 44 mm of TL; 66.82 ± 17.69 mm of CL for males and 204 ± 43 mm of TL; 71.19 ± 17.71 mm of CL for females (Table 4). These average lengths in TL or CL were significantly different between the sexes (Student's t-test: $p < 0.001$).

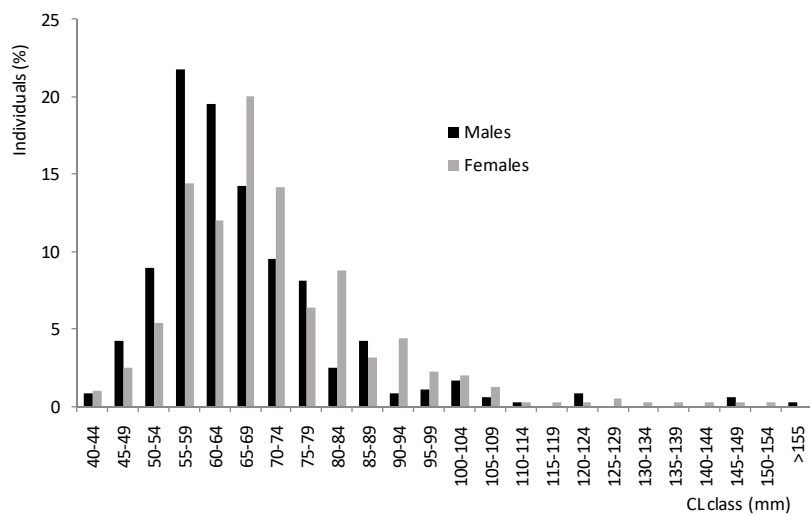


Figure 2:-Distribution of cephalothorax length (CL) frequencies by sex in *P. regius*

Table 4:-Length ranges and average lengths sampled in TL and CL (mm) in *P. regius* (Min = minimum value, Max = maximum value; *** = significant at probability level 0.001)

	Sex	Min.	Max.	Average	p-value
CL (mm)	Males	39.62	290.72	66.82 ± 17.69	***
	Females	42.64	152.70	71.19 ± 17.71	
	Total	39.62	290.72	69.15 ± 17.69	
TL (mm)	Males	112	425	185 ± 44	***
	Females	123	422	204 ± 43	
	Total	112	425	195 ± 44	

Relationship between CL and other biometric variables:

In table 5 are presented the regression parameters between cephalothorax length and the six (6) following variables: cephalothorax width, second abdominal segment width, total length, abdominal length, second pereopod meropodite length and third pereopod meropodite length. For the last two variables, regenerated pereopods were not taken into counted. There was a significant correlation in both males and females individuals between cephalothorax length (CL) and cephalothorax width (CW) ($r^2 = 0.97$ in males and $r^2 = 0.97$ in females; $p < 0.001$). However, the results of the ANCOVA test showed no significant difference between the slopes of the two regressions ($p > 0.05$). Therefore, there was no sexual dimorphism related to the cephalothorax form. For the five (5) other variables analyzed as a function of CL, the correlations were significant and the linear adjustment line for females was above that of the males, excepted the pereopods (ML₂ and ML₃) where growth was faster in males compared to females. The slopes showed significant differences (ANCOVA test, $p < 0.001$). Females had a relatively longer and wider body than males. However, for the same total length, males were heavier than females. In contrast, in green spiny lobster, as for most spiny lobster, sexual dimorphism on pereopod growth, particularly in the second and third pairs, was very remarkable and was in favor of males, whereas it was less obvious or non-existent with other pairs.

Table 5:-Relationship between cephalothorax length (CL) and other biometric variables in *P. regius* in Petite Côte, Senegal (CW = cephalothoracic width; SW = second abdominal segment width; TL = total length; AL = abdominal length; ML₂ = second pereopod meropodite length; ML₃ = third pereopod meropodite length; N = individuals number; a = slope; b = intercept; r = correlation coefficient; *** = significant at probability level 0.001)

Linear regression	N	a	b	r ²	p-value
CL – CW (males)	354	0.71	1.95	0.97	***
CL – CW (females)	405	0.72	2.39	0.97	***
CL – SW (males)	357	0.59	2.93	0.97	***
CL – SW (females)	407	0.78	-6.04	0.98	***
CL – TL (males)	355	2.59	14.09	0.97	***
CL – TL (females)	407	2.84	1.64	0.98	***
CL – AL (males)	355	1.59	14.08	0.92	***
CL – AL (females)	407	1.84	1.64	0.95	***
CL – ML ₂ (males)	356	0.81	-11.40	0.93	***
CL – ML ₂ (females)	407	0.62	-0.49	0.96	***
CL – ML ₃ (males)	353	0.90	-11.84	0.92	***
CL – ML ₃ (females)	408	0.68	0.68	0.96	***

Reproductive biology:**Length at first sexual maturity:**

Based on the morphological maturity approach and allometry, the respective ML₂ and ML₃ regressions according to CL allowed locating between 55 and 60 mm (CL) the changing zone in the pereopods growth for individuals of both sexes in favor of males. From these results on ML₂ and ML₃, the distribution of males was separated into two subgroups. The first subgroup consisted of individuals whose CL was less than or equal to 55 mm and the second of those whose CL was greater than or equal to 60 mm. The ML₂ (Fig 3A) and ML₃ (Fig 3B) regressions of each of these two subgroups as a function of CL were plotted. The resolution of the equation systems from these respective adjustment lines gave a deflection point at 67.51 mm of CL for ML₂ and 67.62 mm of CL for ML₃. For the ML₂ regression as a function of CL, the slope was significantly different (ANCOVA test, $p < 0.05$) whereas the slope of ML₃ as a function of CL, was not different (ANCOVA test, $p > 0.05$). The same approach was used on the variables SW and AL as a function of CL. The slopes of these regressions were significantly different (ANCOVA test, $p < 0.05$).

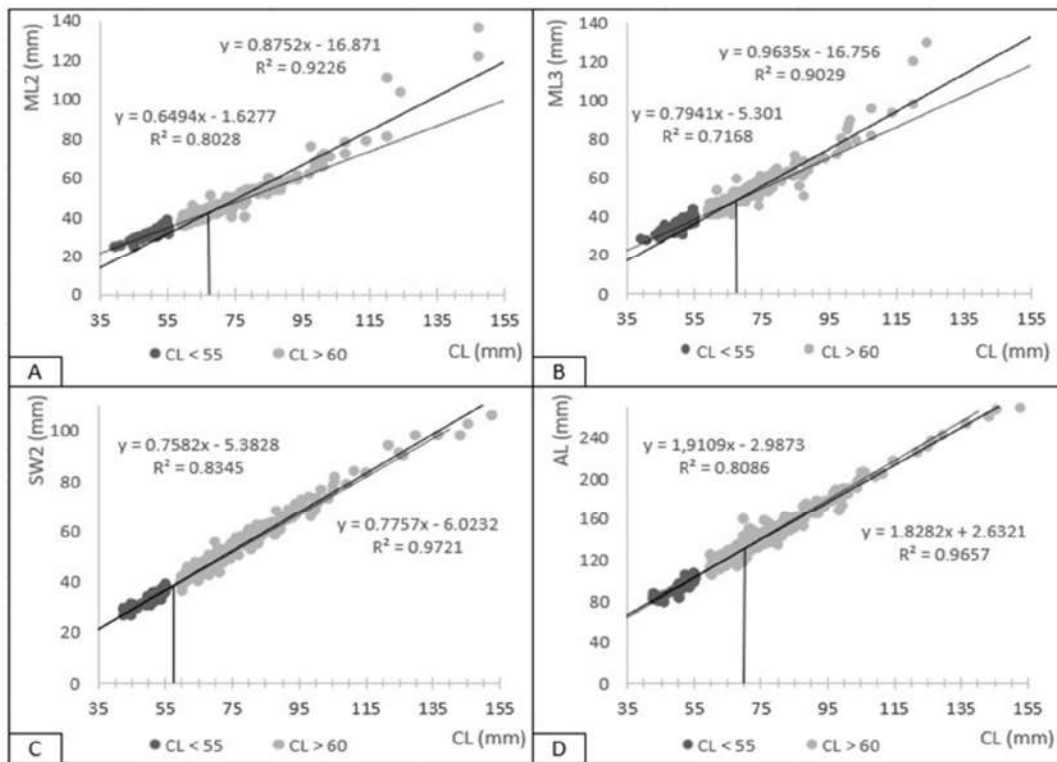


Figure 3:-Determination of length at first sexual maturity in *P. regius* with the morphological approach. In males which using the second meropodite length (ML₂) (A). In males which using the third meropodite length (ML₃) (B). In females which using the second abdominal segment width (SW) (C). In females which using the abdominal length. (AL) (D).

For females, the gait applied to males was repeated for the SW, AL, ML₂ and ML₃ as a function of CL. But, excepted AL, whose deflection point was 67.95 mm (CL), it was not possible to precisely locate the intersection zone of the regression lines between SW - CL, ML₂ - CL and ML₃ - CL. Nevertheless, the result from the regression of AL as a function of CL (Fig 3D) was used as an indication of the length at first sexual maturity because the slopes of these regressions were not different (ANCOVA test, $p > 0.05$).

Based on the functional maturity approach, the smallest female observed in the reproductive phase had a 71.64 mm of CL. The CL₅₀ is estimated at 94.50 mm of CL (Fig 4).

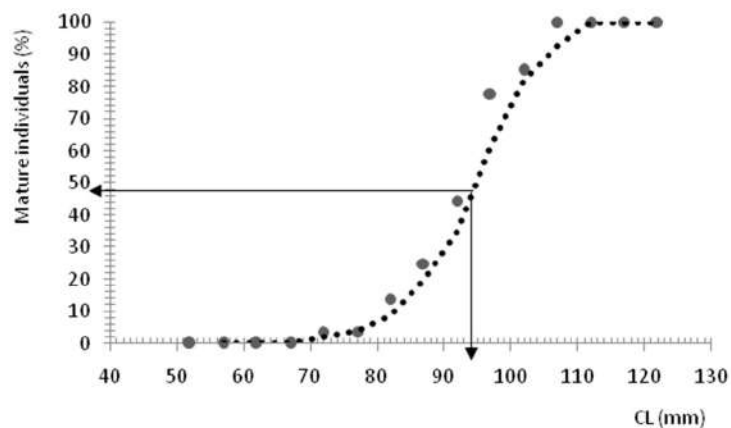


Figure 4:-Logistic curve computed from the percentage of mature individuals and determination of length at first sexual maturity (CL₅₀) with the functional approach during the period of reproduction in females *P. regius*

Sexual maturity stages variation:

The overall percentage of female individuals at sexual maturity stage 2 or upper, in the sample was approximately 11%. Among mature individuals, stage 3 was the most frequently observed (34%) followed by stage 2 (30%). The proportion of mature individuals by month (Fig 5) varied between 7 and 15%. The highest proportion of mature individuals is observed in June.

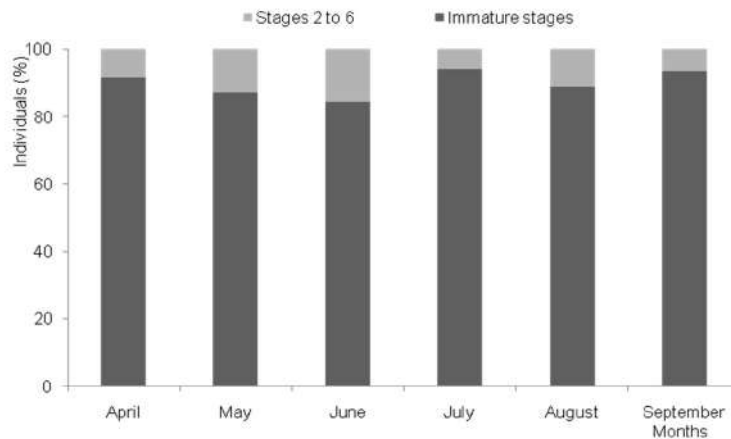


Figure 5:-Monthly variation in percentage of immature (stage 1) and mature (stage 2 to 6) females during the period of reproduction in *P. regius*

Fecundity:

The fecundity study was performed on five (5) ovigerous females that had a CL between 91 and 105 mm and were between stages 3 and 5 of the egg maturation cycle. Their mass varied between 652 and 1 005g. The dry egg mass (DEM) ranged from 7.97 to 23.51g with an average of 14.30 ± 6.79 g and relative egg mass (REM) between 2.73 and 4.61g with an average of 3.75 ± 0.67 g (Table 6). Absolute fecundity or individual fecundity was between 208,371 and 638,775 eggs with an average of $388,594 \pm 182,755$ eggs and relative fecundity between 291 and 643 eggs g^{-1} with an average of 489 ± 172 eggs g^{-1} . It appeared that larger females tend to have higher fecundity and bigger eggs. The number of incubating eggs would also tend to decrease as the egg maturation cycle progressed.

Table 6:-Variation of some fecundity index in *P. regius* according to length and sexual maturity stages (DEM: dry egg mass, REM: relative egg mass, AF: absolute fecundity, RF: relative fecundity)

Stage	CL (mm)	M (g)	DEM (g)	REM (g)	AF	RF
III	96.55	780	19.47	3.88	501.470	643
III	105.03	1.005	23.51	3.68	638.775	635
IV	91.58	653	9.96	2.73	364.529	558
V	91.63	652	7.97	3.83	208.371	319
V	98.49	791	10.59	4.61	229.826	291
Mean	96.66 ± 5.58	776 ± 144	14.30 ± 6.79	3.75 ± 0.67	388.594 ± 182.755	489 ± 172

Discussion:-

Morphometric relationships:

Sample and length structure:

The sampling results showed a significant decrease in the number of individuals recorded in April and September compared to other months of the study period. The low number of individuals recorded in April can be explained by a late start of surveys during this month and an experimenting step in the implementation of the sampling protocol. In September 2017, the sampled number was related to a slowdown in fishing activities noted during several days because of the Eid al Kabir celebration.

The high proportion (64%) of individuals whose TL was below the minimum legal landing length (200 mm of TL) under the Senegalese Fisheries legislation (Anonyme, 1998, 2015), was probably due to the use by fishermen of mesh nets below the authorized threshold (Thiao et al., 2017). Length structure (CL) showed a preponderance of males in

lengths ≤ 65 mm. Beyond this length, the sex-ratio turned in favor of the females. For lengths > 155 mm of CL no female was recorded. These results were similar to those of Marchal and Barro (1964) who found a preponderance of males up to 170 mm TL and did not observed any female with a greater than 300 mm TL, which approximately corresponds to a 100 to 115 mm CL.

The average length landed (CL) of females overall greater than that of males would be more related to a preponderance of small length males in the sample than a faster growth of females. In fact, 74% of landed males had a less than or equal to 200 mm (TL) against 55% for females. Moreover, by comparing the condition factor of the regression line equations of the length-mass relationship, males appeared to have higher growth potential than females as suggested by Marchal and Barro (1964) in Côte d'Ivoire and Dia et al. (2015) in Mauritania. Indeed, these authors found respectively a higher condition factor in males compared to females.

These results could, therefore, mean that within small individuals, the probability of catching males was higher than that of females, because small individuals are captured in shallow areas, according to the testimonies collected from local fishermen during sampling.

However, it is accepted that the spiny lobster migrates in deep water for a part of reproductive cycle (Melville-Smith and Beale, 2009). So, recruitment of new cohorts into the reproductive biomass could, therefore, be earlier in females and more selective in males, almost exclusively devoted to large dominant males.

Length - mass relationship:

The male individuals appeared heavier than females for the same TL. This result was similar to those of Marchal and Barro (1964) on green spiny lobster stock in Côte d'Ivoire and Da-Franca et al. (1962 in Postel 1966) in Cape Verde stock. One of the given reasons was that moults were more spaced in females because of the eggs bearing which prevents them from moulting for long periods. This probably could make their growth slower compared to males. The other reason was that for the same TL, males had a larger cephalothorax which could allow them to be heavier than females. However, the female individuals seem heavier than males for the same CL. This could be due to a morphological adaptation related to the breeding period (incubation of eggs) where lengthening and enlargement of the abdomen compared to males gave them a significant body mass gain. This fact has been observed by Jayakody (1989) in *Panulirus homarus* in which the faster growth of the abdomen of females was associated with the acquisition of sexual maturity. The fact that females had a relatively longer and wider body than males was consistent with Berry's (1973) observations in *Palinurus delagoae*. This difference in growth appeared approximately at 50 mm CL.

From a morphological point of view and referring to the TL, males could be considered to have the best growth rate. But, from an economic point of view, the female's morphology was more interesting because their edible mass was greater than those of males, due to a better growth of the pleon.

The change in growth rate in pereiopods was more remarkable in the second and third pairs of pereiopods. This change is generally observed between 55 and 60 mm and is interpreted as a changing towards sexual maturity in males (George and Morgan, 1979).

The purpose of these morphological changes between juvenile stage and first sexual maturity stage was for males to be capable of mating and transferring spermatophores to the female. For females, it corresponded to the enlargement of contact surface for egg incubation in the abdomen (Jayakody, 1989).

Length at first sexual maturity:

The results from the morphological maturity approach indicated that males and females reached the first sexual maturity at comparable lengths (67.51 mm in males and 67.95 mm in females). This could mean that morphological changes related to reproduction occur at the same period of life cycle in both sexes. However, none study on *P. regius* that we have access have examined the sexual maturity in males.

The estimated CL_{50} in females was 94.50 mm. This index was the most commonly used to study functional maturity in *P. regius*. The difference between the CL_{50} (functional maturity) and the length at first sexual maturity (morphological maturity) was 27 mm in favor of the CL_{50} .

These results were consistent with those of Kizhakudan and Patel (2010) who found a functional maturity length (CL_{50}) higher than morphological maturity length (body allometry). This difference can be explained by the method

used to determine the length at first sexual maturity. In this study, the length at first sexual maturity was determined from the indices of morphological maturity (allometry) and functional maturity (CL₅₀). With the use of the latter one, the existence of a lag phase between the morphological maturity length and the first spawning length could explain this difference as suggested by Evans et al. (1995). Indeed, during this latency phase, moults would be likely to give a significant growth gain, which allowed finding a higher length of functional maturity than the morphological one. In addition, the irregularity of reproductive activity in relatively smaller females mentioned by McDiarmid and Sainte-Marie (2006) and Perez-Gonzalez et al., (2009) can also help to explain this difference between CL₅₀ and morphological maturity length. Indeed, this phenomenon would lead to an overestimation of the CL₅₀, which would be greatly increased by the large female's proportion.

In males, morphological maturity is often assimilated to functional maturity because the lengthening of the 2nd and 3rd pairs of pereopods also reflects its ability for mating. By contrast, even if the morphological aptitude for mating is acquired, it does not seem to guarantee the recruitment in the reproductive biomass. That is probably why in a shallow zone, the sex-ratio was clearly in favor of the males. This could mean that reproductive activity is essentially provided by a relatively small proportion of dominant large males.

For females, however, the best index to determine sexual maturity appeared to be the length at which 50% of individuals are sexually mature during the breeding season (CL₅₀). This index seems more relevant because it could allow stock management measures to preserve sufficient reproductive biomass to sustain the resource and the fishery.

Marchal and Barro (1964) obtained 200 mm of TL₅₀ and Freitas et al. (2007) 87.9 mm CL₅₀ (about 250 mm in TL). These two lengths were smaller than the one found in this study. Differences in the lengths at first sexual maturity observed in different geographical areas may be due to several factors. The difference in growth rate would result from the effects of temperature and nutrient availability across geographic areas as suggested by Robertson and Butler (2003) and Freitas et al. (2007). However, according to Freitas et al. (2007), there was a small latitudinal temperature gradient from Mauritania to Angola which corresponds to the distribution zone of *P. regius* on the African coasts and therefore it had a weak influence on the CL₅₀. Also, the intensity of the fishery exploitation regime, coupled with natural predation, would induce an adaptation in spiny lobster populations towards early sexual maturity, which would result in a decrease of length at first sexual maturity (Hogarth and Barratt, 1996). This phenomenon could explain the relatively large gap in the CL₅₀ between our results and those of Freitas et al. (2007). However, it remains to be established whether the fishing pressure on the Cape Verdean stock was greater than that exerted on the Senegalese Petite Côte' stock.

The length of the smallest ovigerous female in this study was 210 mm of TL. This length was comparable to those found in Mauritania (Diop and Kojemiakine, 1991; Dia et al., 2015) and in Senegal by Clotilde-Ba et al. (1997). However, it was higher than those found by Marchal and Barro (1964) with 160 mm of TL in Côte d'Ivoire, Crosnier (1971) with 150 mm of TL in Congo and Freitas et al. (2007) with 61.9 mm (CL) or about 180 mm of TL in Cape Verde.

Fecundity:

Individual fecundity was between 208,371 and 638,775 eggs with an average of $388,594 \pm 182,755$ eggs. The results on individual fecundity were comparable to those of Freitas et al. (2007) from Cape Verdean coasts. These authors estimated that the average number of eggs for individuals with CL between 90 and 95 mm was 440,000 eggs and 509,000 for those with CL between 95 and 100 mm and finally 667,000 for those with CL between 105 and 110 mm.

Studies on *P. regius* fecundity on Mauritanian coasts made by Dia et al. (2015) recorded 346,000 and 266,000 eggs in females of 94 mm CL at sexual maturity stages 3 and 4, respectively. This seems to indicate a lower fecundity compared to the $388,594 \pm 182,755$ eggs found in this study. By contrast, the fecundity reported by Marchal and Barro (1964) from Côte d'Ivoire was 416,000 eggs in a female of 81 mm CL. This fecundity value seems to be the highest of observations made in the geographical area from Mauritania to Angola. But, it is important to note that this fecundity recorded by Marchal and Barro (1964) could be biased because the estimate was based on one (01) ovigerous female against five (05) in this study, 26 and 65 for Dia. et al. (2015) and Freitas et al. (2007), respectively.

The small number of individuals used in this study to estimate fecundity did not allowed making an analysis of the covariance between morphometry, eggs maturation cycle and different indices such as DEM, REM, AF, RF.

The mass of individuals appeared to be positively correlated with AF and REM, which would mean that larger females would have higher fecundity and bigger eggs. This advantage may be due to a larger egg litter and greater egg attachment area in larger females compared to smaller individuals. In contrast, the stages of eggs maturation seemed to be negatively correlated with AF. It appeared that the amount of eggs decreased as hatching approached. This trend was the same as that observed by Dia et al. (2015) who explained this phenomenon by the possibility of egg loss during the incubation cycle. The average REM index recorded in this study with females from 90 to 100 mm CL was 3.76 ± 0.77 . It was higher than that noted by Freitas et al. (2007) which was 2.71 ± 0.19 for females with CL between 80 and 100 mm. The small number of individuals used to estimate the fecundity in this study nevertheless cannot lead to definitive conclusions on this point.

Conclusion:-

In sum, green spiny lobster, *P. regius*, is one of the important fishery resources in Senegal, from a socio-economic point of view. It is a marine species whose distribution is observed along the Senegalese coasts.

The biometric study showed visible sexual dimorphism from 50 mm of CL. This dimorphism reflected some morphological adaptations for reproduction. Sexual maturity in the physiological sense is not studied here, but it seemed to precede morphological maturity. According to the morphological approach, the length at first sexual maturity in males (67.51 mm CL) and females (67.95 mm CL) were awfully close. From the functional approach based on the observations of several reproductive indicators in females, the length at first sexual maturity was significantly higher compared to that estimated from the morphological approach (71.64 mm CL for the smallest ovigerous female and 94.50 mm for the CL₅₀).

According to the results of this study on the length at first sexual maturity in females (TL₅₀ = 270 mm), it would be desirable to increase the legal minimum landing length in *P. regius*, which is currently in 200 mm of TL in Senegal. This measure could help to preserve sufficient reproductive biomass to ensure the sustainable balance of the green spiny lobster fishery in Senegalese Petite Côte.

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