Population Dynamics of Spiny Lobster, *Panulirus regius* de Brito Capello, 1864 in the Gulf of Guinea off Côte d'Ivoire (West Africa)

Ida Akissi KONAN[1], Olivier Assoi ETCHIAN[1], Basile Kouakou KOUAME[1], Angelina Gbohono LOUKOU[1], Christian Bernard TIA[2]

[1]University NANGUI ABROGOUA, Formation Unit and Research of Nature Sciences Laboratory of Biology and Animal Cytology, 02 BP 801 Abidjan 02, Côte d'Ivoire
Email: idaakissikonan[AT]gmail.com

[1]University NANGUI ABROGOUA, Formation Unit and Research of Nature Sciences Laboratory of Biology and Animal Cytology, 02 BP 801 Abidjan 02, Côte d'Ivoire
Email: oetchian[AT]gmail.com

[1]University NANGUI ABROGOUA, Formation Unit and Research of Nature Sciences Laboratory of Biology and Animal Cytology, 02 BP 801 Abidjan 02, Côte d'Ivoire
Email: kouamé_b[AT]yahoo.fr

[1]University NANGUI ABROGOUA, Formation Unit and Research of Nature Sciences Laboratory of Biology and Animal Cytology, 02 BP 801 Abidjan 02, Côte d'Ivoire
Email: loukouangelina[AT]gmail.com

[2]University SAN PEDRO, Formation Unit and Research of Marine Sciences
Côte d'Ivoire
Email: christianbernardtia[AT]gmail.com

ABSTRACT---- *The population dynamics of the spiny lobster Panulirus regius were studied. A total of 331 individuals divided into 195 males and 136 males with respective lengths ranging from 14 cm to 38.4 cm and from 12.9 to 23.4 cm were used for this study. Sampling took place over a 12-month period from August 2019 to September 2020 at the Assinie landing site among artisanal fishermen operating in the Gulf of Guinea in Côte d'Ivoire. The FiSAT II software was used to determine the growth and exploitation parameters. The results showed an identical modal class [15-18] for both sexes and even for the total population. The growth parameters were performed according to the Von Bertalanffy growth model. The asymptomatic length determined was L∞ = 39.38 cm for a growth coefficient K = 0.38 year-^{1} with a performance index Φ'=2.77 years. The theoretical age for zero length was t_0 = -0.40 years while the longevity tmax = 7.89 years. Total mortality (Z) is 1.42 year-^{1} and natural mortality (M) is 0.89 year-^{1}. However, fishing mortality (F) is 0.53 year-^{1}. The current exploitation rate (E) is 0.38. As regards recruitment, a peak was obtained in February with a value of 15.71%.*

Keywords--- Spiny lobsters; Panulirus regius; Growth, Exploitation

1. INTRODUCTION

Among the Palinuridae spiny lobsters Latreille 1802, the genus *Panulirus* White 1847 is the most diversified with 24 species/subspecies [1]. External secondary features differenciate the clawed lobsters of the Family Nephropidae from Palinurid lobsters. Unlike the clawed lobsters, spiny lobsters do not possess sperm receptacle on the sternum of females and pleopods of males are not involved in sperm transfer [2,3]. Spiny lobsters of the genus *Panulirus* are found in shallow tropical and subtropical waters at a depth of less than 100 m of both hemispheres, where the diversity of habitats may have promoted a greater radiation of this genus [4,5,6]. These are an economically species supporting subsistence or large-scale fisheries [7,8]. The consumption of these food sources of high nutritional prevents heart diseases [9]. Despite their high commercial value, little research has been done on the population dynamics of spiny lobsters.

Panulirus regius De Brito Capello 1864 is a palinurid lobster considered by [10] as an Atlantic-Mediterranean species. The royal spiny lobster, *P. regius* is encountered in the western Mediterranean and in the south of the Strait of Gibraltar from Morocco to Angola including the Cape Verde Islands [11,12,13]. This marine crustacean prefers rocky areas with agitated and continuously stirred coastal waters. It is most abundant at depths between 8 and 10 m [14] and weakly concentrated at 25-30 m depth [15]. *P. regius* is an economically important spiny lobster exploited in the Gulf of Guinea [16,14,17]. Despite its high nutritional value [18], little is known about the population dynamics of *Panulirus regius* off West Africa. Indeed, according to [19], estimates of growth parameters provide essential insights into fishery resource dynamics and can be used as input for fisheries assessment models. Therefore, the aim of our work was to determine some growth parameters like the distribution of size and the parameters of growth and exploitation of the royal spiny lobster, *P. regius* exploited in the Gulf of Guinea off Côte d'Ivoire.

2. MATERIAL AND METHODS

2.1 Study area

Côte d'Ivoire is a tropical country located in southern West Africa and its southern border is a 515 km long coastline on the Gulf of Guinea in the North Atlantic Ocean (Figure 1). The Gulf of Guinea ecosystem extends from Bissagos Island (Guinea-Bissau) (latitude 11°N, longitude 16°W) to Cape Lopez (latitude 0°41'S, longitude 8°45'E) [20,21]. Four marine seasons are found in the area: a short cold season (SCS) occurring from January to February (minor upwelling), a long warm season (LWS) between March to June, a long cold season (LCS) from July to October (major upwelling) and a short warm season (SWS) in November to December. Specimens were sourced from the artisanal fisheries operating in the exclusive economic zone (EEZ) off Assinie (Figure 1). This city (5°7'25" N and 3°16'40"), located 80 Km east of Abidjan along the coast of the Gulf of Guinea, is chosen because the specimens are regularly present in the landings throughout the year.

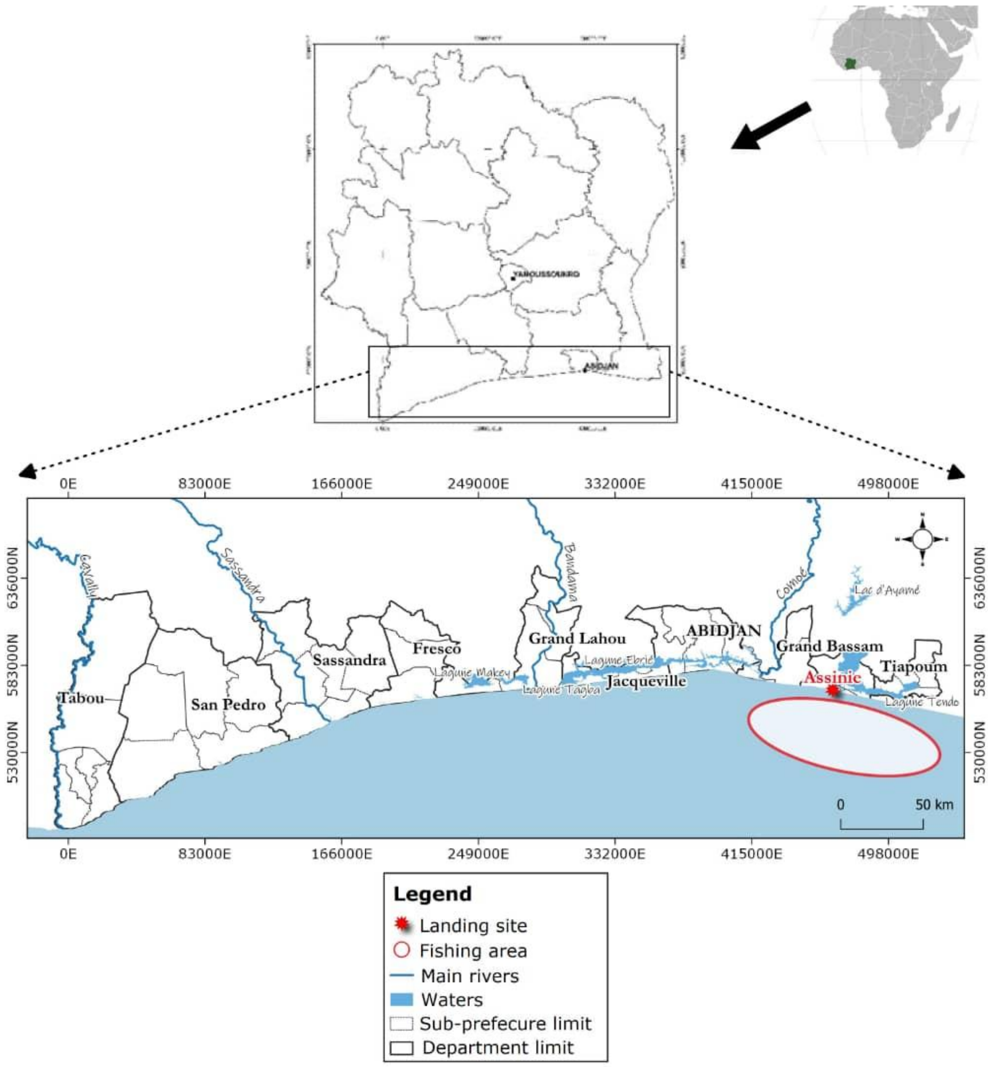


Figure 1: Geographical location of the study area

2.2. Spiny lobster collection

Specimens of *P. regius* were sampled on monthly basis from September 2019 - August 2020. Fishing was carried out by a group of four to five fishermen operating with one artisanal boat. The capture of the specimens consists of setting the nets at dusk, left overnight and lifted the following morning at the first light of dawn. The captured lobsters were kept in storage nets for conservation and were then brought back on Assinie beach. Individuals sampled were identified [22], kept in a cooler filled with ice and rapidly transported to the laboratory for analysis. Once a month, 25 animals were approximately collected and a total of 331 individuals obtained during the study period. Biometric parameters like total weight (TW ± 0.1 g), carapace length (CL ± 0.1 cm) and total length were recorded for each spiny lobster.

2.3. Data analysis

The number of classes and class internal were obtained using the formula of Sturge [23] in the construction of the size frequency distribution. Size frequencies were used to create a dynamic cross-tabulation table using Excel software. Data were then analysed using FiSAT II software (FAO-ICLARM Stock Assessment Tools) 24 25 (Gayanilo et al., 1996; Loukou et al., 2021).

2.4. Growth parameters

The growth coefficient (K) and asymptotic length (L∞) were estimated with the ELEFAN I module of FiSAT-II software [26] using the growth function of Von Bertalanffy (vBGF) [27] defined as $Lt = L\infty(1 - e^{-K(t-t0)})$, where : Lt = length at age t; L∞ = asymptotic length (cm) when it reaches t years, K = growth coefficient (year^{-1}) and t0 is the theoretical age at which the spiny lobster would have had at zero length. This value was obtained by Pauly's empirical equation [28]: $\text{Log}_{10}(-\text{t}0) = -0.392 - 0.275\ \text{Log}_{10}\text{L}\infty - 1.038\text{Log}_{10}K$. The lifespan (longevity Tmax) indicating the age at which 95% of the asymptotic lenght L∞ is reached, was estimated following Pauly's equation [29] : Tmax (in year) = 3/K. The formula developed by [30] was used to calculate the length based growth performance index Phi (ϕ): $\Phi' = \log_{10}(K) + 2\log_{10}(L\infty)$.

2.5. Exploitation parameters

The total mortality rate (Z) was estimated using length-converted catch curve method as implemented in FiSAT II, while the empirical formula of [29] showing the effect of annual temperature was perfomed in determining the natural mortality rate (M): $\text{Log}_{10}M = -0.006 - 0.279\ \text{Log}_{10}\text{L}\infty + 0.6543\text{Log}_{10}K + 0.4634\text{Log}_{10}T$, where: T= the mean annual temperature of coastal waters in Côte d'Ivoire (28.5°C). Mortality due to fishing (F) was deduced from the expression written as F=Z-M, the exploitation ratio (E) from E=F/Z and the survival rate as: S = exp (-Z). [31, 32]. When E = 0.5, the exploitation of the stock is optimal (F = M), E < 0.50 (F < M) expresses low exploitation (under fishing) and E > 0.50 for high exploitation (F>M) [33,34]. The exploitation rate (E) can also be divided into five categories of fishing status: no exploitation (E = 0.00), (b) low exploitation (0.00 <E < 0.50), (c) optimal exploitation (E = 0.50), (d) high exploitation (0.50 < E < 1.00), and (e) stop exploitation (E = 1.00). The values of Relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R) were obtained from the estimated growth parameter and probabilities of capture by length [35,36]. The analysis of the Y'/R and B'/R is done with the FISAT II program. The optimal catch size (Lopt) was obtained from the formula of [37]: Lopt = L∞ (3/3+M/K), where : Lopt = optimal catch size (cm), M : natural mortality (year^{-1}) and K = growth coefficient (year^{-1}). The reproductive potential of individuals was checked by using the lenght at first sexual maturity SL_{50} indicating the lenght at which 50% of the specimens are mature [38]. The SL_{50} was determined by using mature individuals based on gonad histology and a logistic regression analysis [39]: $P = \frac{1}{1+e^{(a+bL)}}$ and SL_{50} = - a/b, where L = lenght (cm); a and b are constants. The SL_{50} value was then compared to the lenght at first capture (Lc). The studied species is overexploited when Lc < SL_{50} and under exploited for Lc > SL_{50}.

3. RESULTS

3.1. Length frequency distribution of *P. regius*

A total of 331 specimens of *Panulirus regius* was collected during the study period, including 195 females and 136 males with total lengths (TL) ranging from 14 to 38.4 cm and from 12.9 to 23.4 cm, respectively. In population, the smallest specimen measured 12.9 cm TL and the TL recorded for the largest individual was 38.4 cm. Of the total, 64 males and 96 females were caught in the cold seasons and we noted 72 males and 99 females in warm seasons. The female, male and total populations were divided into 9 TL classes. A unimodal TL distribution was observed in the population with a modal TL class of 15-18 cm for each sex (Fig. 2). In addition of the common modal class, the females are more present in TL class of 18-21 cm and the males represented in the TL classes of 12-15cm and 18-21 cm and the TL class of 18-21cm in total population. In the study area, the size of first sexual maturity (SL_{50}) was 19.70 cm TL for female individuals, 17.80 cm TL for male specimens and 19.01 cm TL for population (Fig. 3).

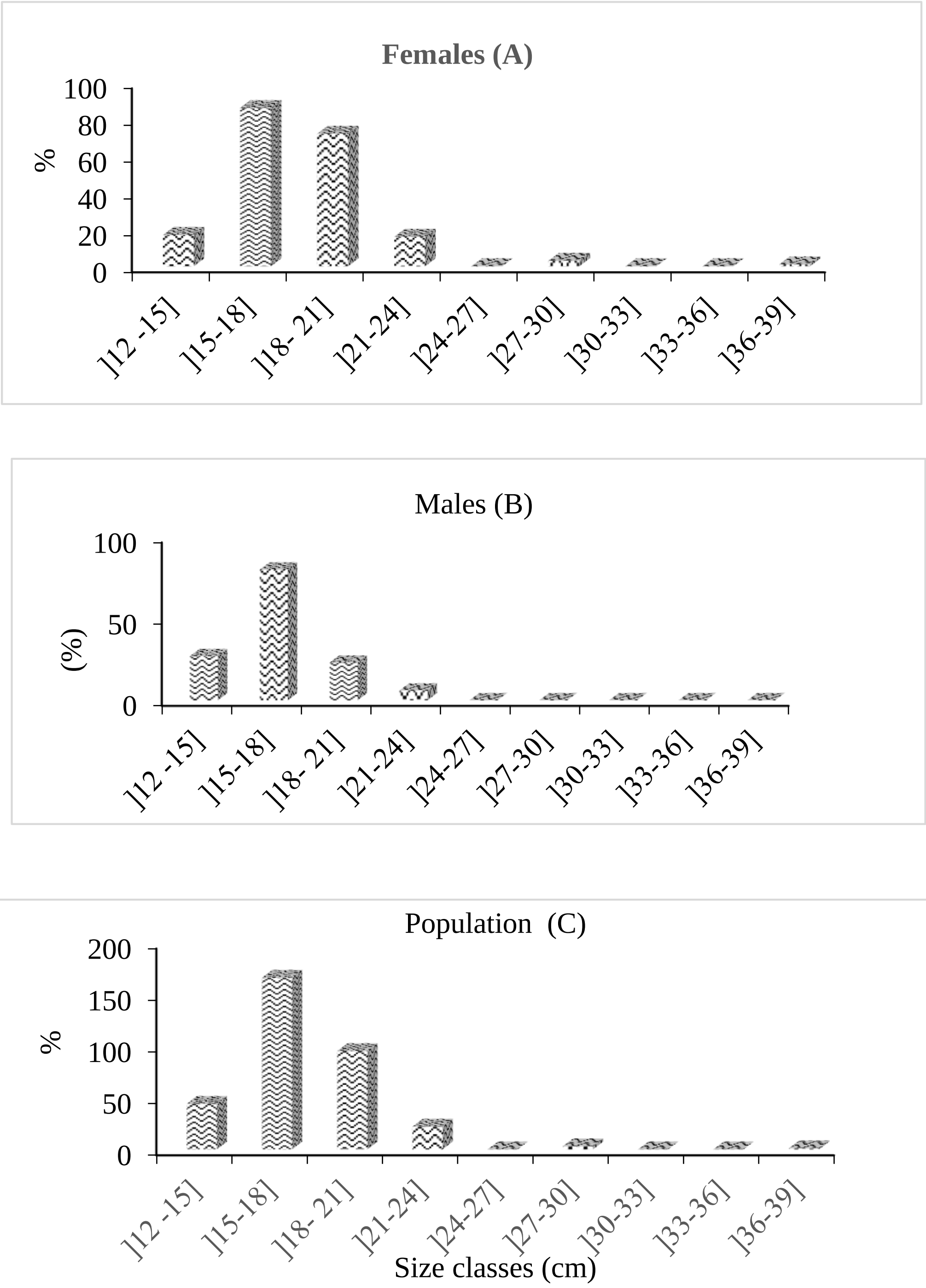


Figure 2: Lenght frequency distribution (%) of *P. regius* in the study area. A : Female individuals, N=195; B: Male individuals, N=136; C: All specimens sampled, N= 331.

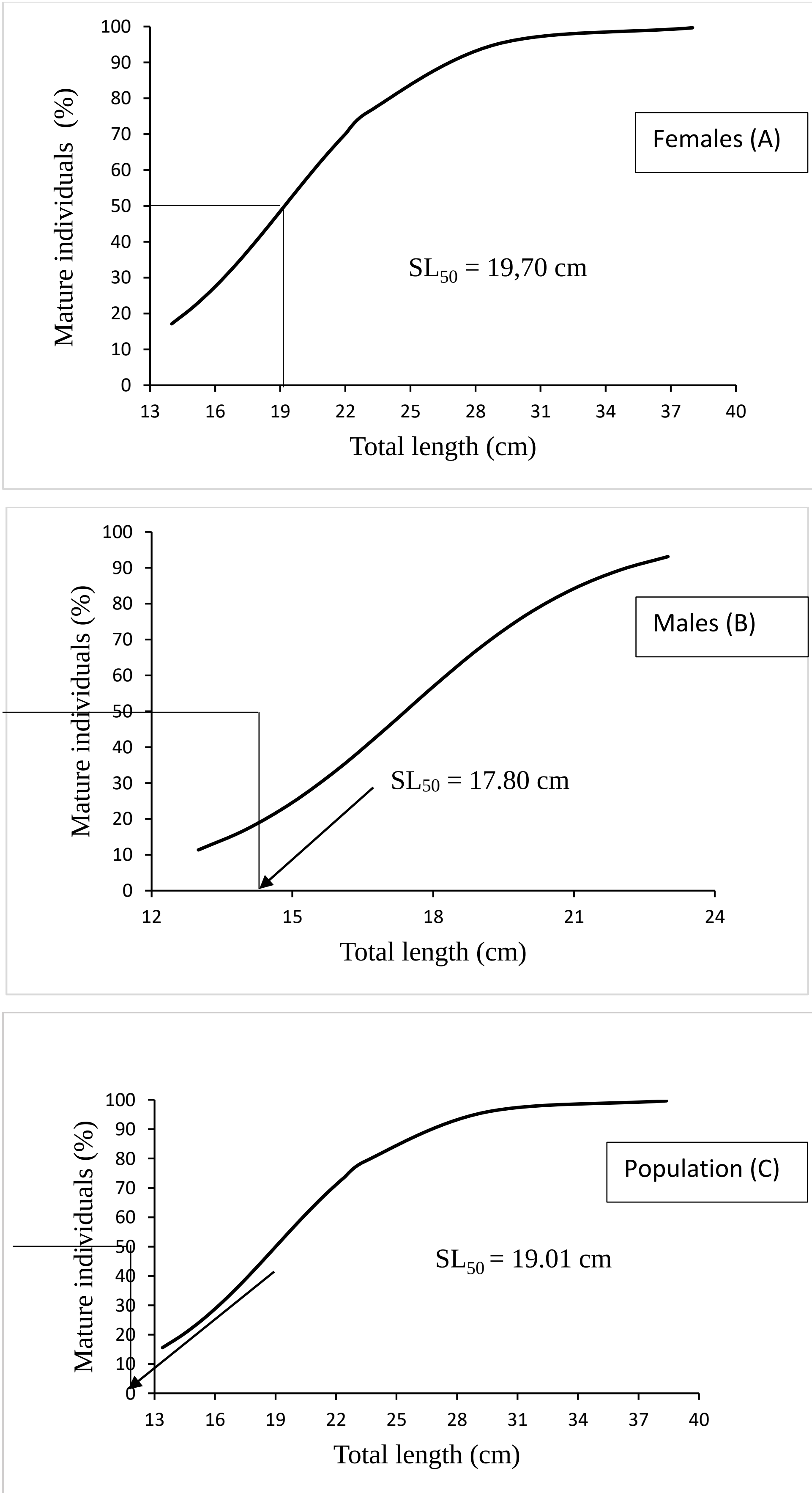


Figure 3: Total length for the first sexual maturity (SL_{50}) of the spiny lobster *P. regius*

3.2. Growth parameters of *P. regius*

The asymptotic length (TL∞) and the growth coefficient (K) of the spiny lobster *P. regius* were 39.38 cm and 0.38/year (Table 1). These two parameters were used to produce the restructured Von Bertalanffy growth (VBG) curves with the length frequency distribution (Fig. 4). The goodness of fit index (Rn) (0.364), the growth performance index (Ø') (2.77 cm/year), the maximum age (T_{max}) (7.89 years) and the theoretical age t0 (-0.4 year) were also indicated in Table 1. The maximum observed TL of 38.4 cm was observed in female individuals, which was lower than the asymptotic length (TL∞ = 39.38 cm TL). The length of the largest male *P. regius* caught during the study period was 23.4 cm TL. The von Bertalanffy growth model for the spiny lobster *P. regius* sampled in the Gulf of Guinea during the present work was estimated as $Lt = 39.38(1 - e^{-0.38(t+0.4)})$ (Fig. 5).

Table 1. Growth parameters of *P. regius* in the Gulf of Guinea

Growth parameters	TL∞	K	Rn	t0	T_{max}	Ø'
Population	39.38	0.38	0.364	-0.4	7.89	2.77

TL∞: Asymptotic lenght (cm); K: Growth coefficient ($year^{-1}$), Rn: Indice de la routine ELEFAN 1; t0: Age at zero total lenght (year); T_{max}: maximum age (year); Ø': Growth performance index.

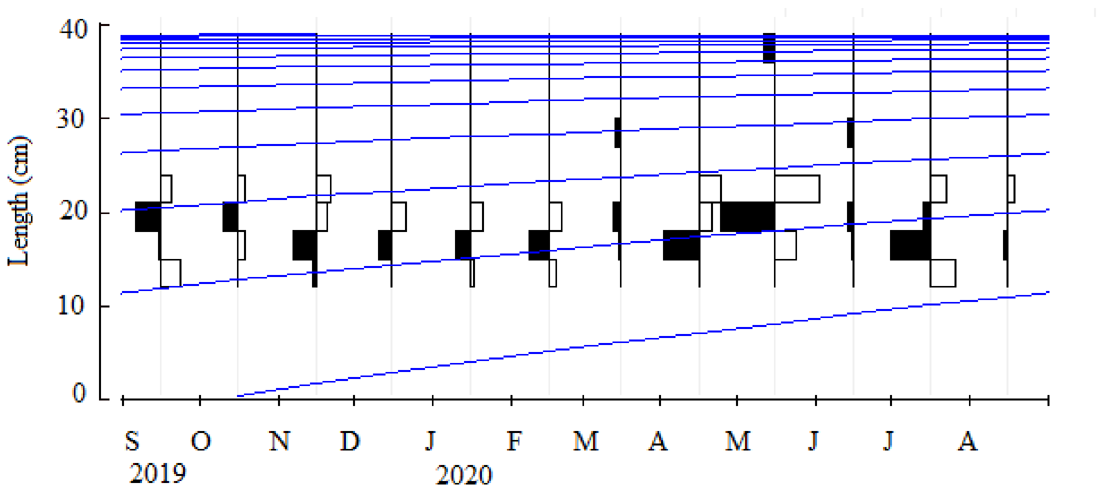


Figure 4 : von Bertalanffy growth curves of spiny lobster drown over their restructured length distribution. Histograms present observed and theoretical size frequencies with positive value in black and negative value in white. Blue lines represent the growth curves indicating the cohorts (all individuals from the same spawning period).

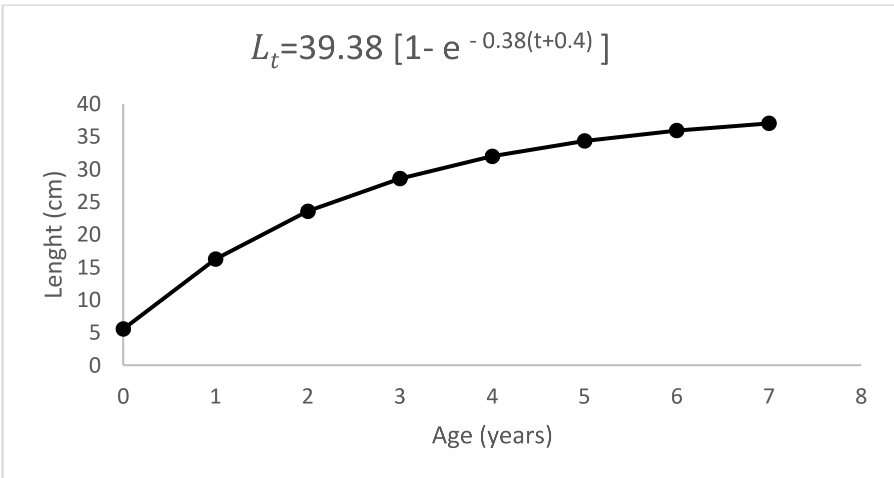


Figure 5: Estimated growth curve of spiny lobster (*P. regius*) exploited in the study area.

3.3. Exploitation parameters of P. regius

3.3.1. Mortality and exploitation parameters

The total mortality (Z), determined with the linearised length-converted catch curve (Fig. 6), estimated a mortality rate of Z = 1.42 $year^{-1}$ for *P. regius*. The natural mortality (M) obtained by using an average annual surface water temperature of 28.5ºC and fishing mortality (F) were calculated to be M = 0.89 $year^{-1}$ and F = 0.53 $year^{-1}$ (Table 2). This result showed that the fishing mortality (F) is much lower than the natural mortality (M). The M/K (2.34) ratio was within the range of 1.12 to 2.50 and the estimated Z/K ratio of 3.74 was more than 2 (Table 2). The current fishing exploitation estimated (E_{est}), derived from the analysis of mortalities rate, was computed as E_{est} = 0.38 (Table 3). The survival rate (S) was calculated as S = $e^{(-1.42)}$) = 0.24 (Table 3). The E_{est} value (0.38) was lower than the optimal rate of exploitation (E_{opt} = 0.5), indicating that the spiny lobster *P. regius* was under exploited in the study area.

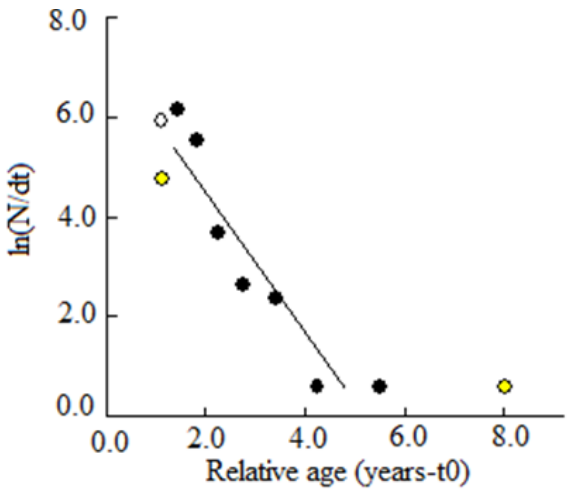


Figure 6 : Linearized catch curve as the determinant of mortality rate of *P. regius*. Black point indicated as mortality by fishing activities and the yellow point is mortality caused by old ages. Z = 1.42/year; M (28.5ºC) = 0.89/year; F = 0.53/year ; E= 0.38.

Table 2. Mortality rates and related parameters of *P. regius*

Parameters	M	M/K	Z	F	Z/K
Population	0.89	2.34	1.42	0.53	3.74

M: Natural mortality ($year^{-1}$); Fishing mortality ($year^{-1}$); K: Growth coefficient ($year^{-1}$); Z: Total mortality ($year^{-1}$)

Table 3. Exploitation parameters of *P. regius*

Parameters	E_{est}(F/Z)	E_{opt}	Status	S	L_{25}	L_{50} (L_C)	L_{opt}	L_{75}	SL_{50}	Status
Population	0.38	0.5	E_{est}<E_{opt}	0.24	11.39	14.06	22.12	16.36	19.01	L_C<SL50

E_{est}: Current estimated exploitation rate; $E_{opt:}$ Optimal rate of exploitation; S: Survival rate; Lc (L_{50}): Length at first capture; Lopt: Optimal catch lenght; SL_{50}: Lenght at first sexual maturity.

3.3.2. Recruitment pattern

The juvenile recruitment of *P. regius* into the exploitable population is illustrated in Fig. 7. The species is recruited every month throughout the year. The major peak of recruitment occurred in February during the minor upwelling with recruitment strength of 15.71% and the low recruitment level (< 0.31%) was observed in August during the major upwelling period.

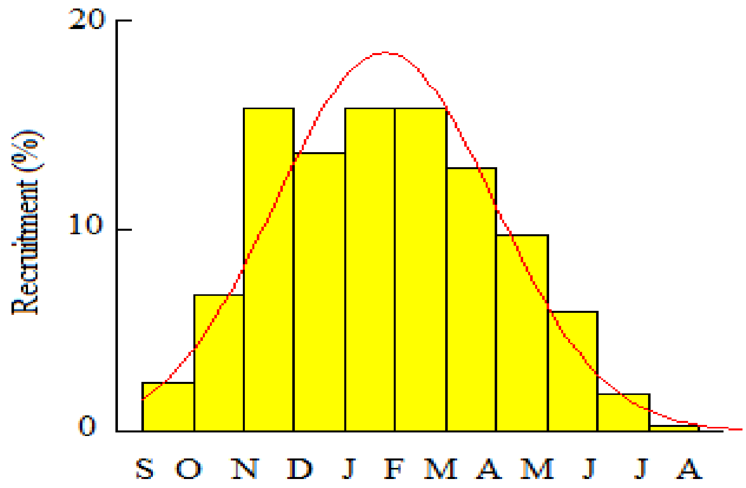


Figure 7 : Recruitment pattern of *P. regius* populations (September 2019 - August 2020) in the Gulf of Guinea. Gaussian distribution smooths recruitment curves for better visualization

3.3.3. Probabilities of capture

The selectivity curve indicating the variation in the probability of capture as a function of the lengths is showed in Fig.8. The length of the first capture (Lc or L50) is 14.06 cm TL. This length corresponds to which 50% of individuals are caught by fishing gear while 50% escape this capture. The lengths at which 25% and 75% of specimens were captured are 11.39 and 16.36 cm TL, respectively and the optimal catch size calculated is 22.12 cm TL (Table 3). The lengths of first sexual maturity (SL_{50}) of 19.70 for females, 17.80 for males and 19.01 cm TL for population were higher than the length of the first capture of population (Lc = 14.04 cm TL), indicating that the spiny lobster *P. regius* was under exploited in the study area.

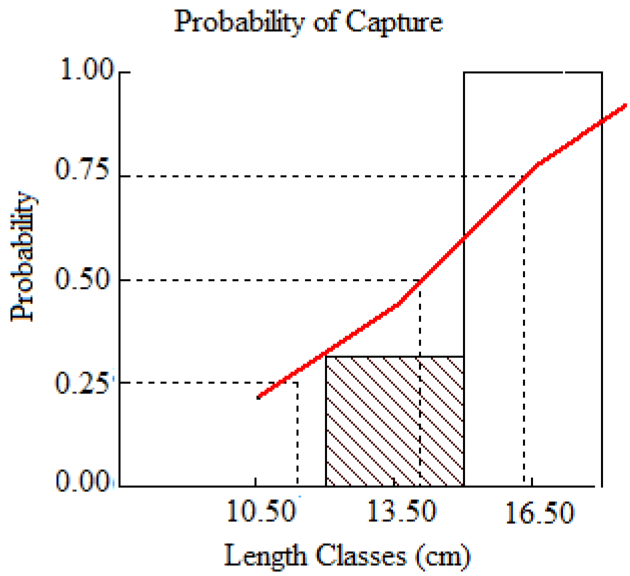
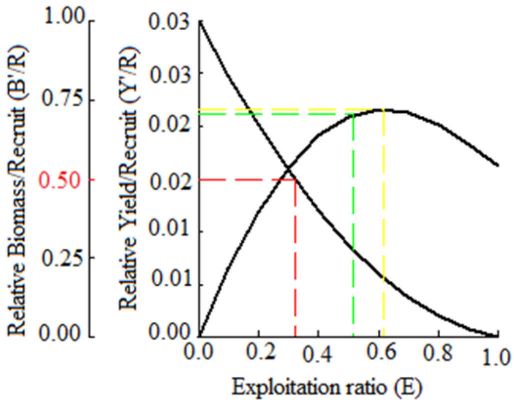


Figure 8: Selectivity curve showing the possibilities of capture for each lenght class of *P. regius* (L_{25} = 11.39 cm, LC ($L_{50)}$ = 14.06 cm, L_{75} = 16.36 cm)

3.4. Relative yield per recruit and the relative biomass per recruit

The results of relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) are showed in Fig. 9. Some fixed parameters used in the equation were M/K ratio = 2.34 and Lc/L∞ ratio = 0.36 with L_C = 14.06 cm TL for a series of exploitation rate E from 0.1 to 1.00 (Table 3). The Y'/R increased with an increase in length and the maximum Y'/R appears at a value of exploitation rate E_{max} = 0.62, which is higher than the current exploitation rate E_{est} = 0.38 (Table 4). The current Y'/R is 0.005 g per recruit while the current B'/R is 0.009 g per recruit. The exploitation rates E50 and E10 yielded values of 0.32 and 0.52 respectively.



Lc/L∞ = 0.36; M/K = 2.34; E max = 0.62; E0.1 = 0.52; E 0.5 = 0.32

Figure 9 : Relative yield per recruit (Y'/R, g/year) and relative biomass per recruit (B'/R, g) for *P. regius* sampled from septembre 2019 to August 2020 in the Gulf of Guinea

Table 4: Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) predicted at different exploitations rates for the spiny lobster, *P. regius*

E	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
Y'/R	0.007	0.012	0.016	0.018	0.020	0.02	0.019	0.017	0.014	0.012
B'/R	0.815	0.649	0.501	0.373	0.265	0.176	0.107	0.056	0.021	0

E: Exploitation rate ; Y'/R : Relative yield per recruit ; B'/R : Relative biomass per recruit.

3.5. Analysis of virtual populations

Figure 10 shows the results of the analysis of the virtual populations of *P. regius* in the study area. The histogram shows the survivors, the population lost due to natural mortality and fishing catches. The fishing mortality (F) curve is superimposed on the cumulative histogram. The natural mortality is high in juvenile individuals and decreases as the length increases. Fishing mortality (1.9/year) is more pronounced in adult specimens with a length of 19.5 cm TL. Individuals with sizes varying from 25.5 to 31.5 and 31.5 to 37.5 cm TL showed low fishing mortality with values of 0.4 and 0.6 $year^{-1}$, respectively.

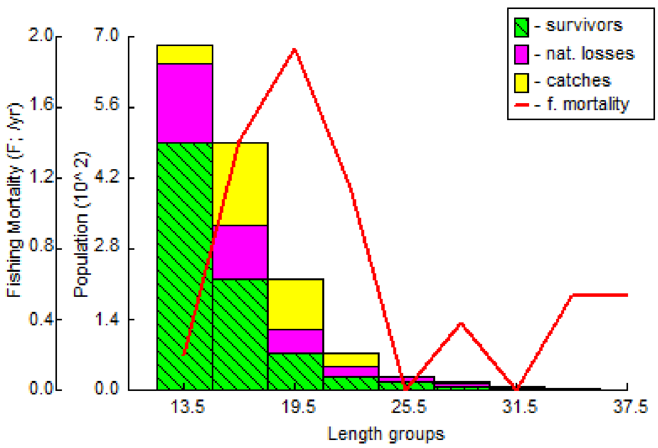


Figure 10 : Virtual population analysis of *P. regius*

4. DISCUSSION

The length total (TL) frequency of *Panulirus regius* sampled in the Gulf of Guinea off Côte d'Ivoire exhibited a unimodal distribution, with the modal class between 15 and 18 cm TL for either sex. This unimodal distribution was also observed by [16] with a modal class between 16 and 19 cm TL for *P. regius* sampled in marine waters off Sassandra, located in the western coast of Côte d'Ivoire. The largest female *P. regius* caught in this study has measured 38.4 cm and the value of 23.4 cm TL was recorded for male *P. regius*. In Mauritanian marine waters, the largest female *P. regius* was found to be 28.2 cm TL in the specimens sampled by [15]. [40] and [41] argue that the maximum size of spiny lobsters in an exploited population depends on the state of its exploitation, the frequency of pruning, habitat and depth. In general, the males *P. regius* are larger than female individuals and grow faster [16,15]. According to [16], the slow growth of females *P. regius* is due to molts more widely spaced in females because the presence of eggs prevents them from molting over long periods. The predominance of males in the larger sizes seemed to associated to their greater longevity [14]. According these authors, males *P. regius* are more abundant at depths of 150 to 250 meters, while large females and immatures are found over 300 meters. The length at first maturity ($SL_{50)}$ is recognized as an important indicator of the reproductive capacity of spiny lobsters and an important tool in stock assessment [42,43]. The value of SL_{50} (19.01 cm TL) recorded in the population of *P. regius* was similar to that reported for the same species in Nouadhibou coasts in Mauritania [15]. This size was estimated at 16 cm TL for *P. regius* caught in the western coast of Côte d'Ivoire [16] and in the southern Gulf of Guinea [44]. Our findings also showed that the SL_{50} was smaller in males (SL_{50} = 17.80 cm) than in female (SL_{50} = 19.70 cm TL) (Fig.3). This suggest that males attain sexual maturity earlier than females as already reported for *Panulirus* species [45]. Indeed, reproduction in *P. regius* could be more costly to female that it is to male. In Côte d'Ivoire, fishing of ovigerous females is prohibited but not for the size. The minimum legal length of 21 cm total length is usually practiced in spiny lobster fisheries [46].

Our work represents the first attempt to analyze the parameters of the von Bertalanffy equation of the royal spiny lobster *P. regius* in the Gulf of Guinea using the FiSAT-II software. The asymptotic length ($L\infty$) and growth coefficient (K) were estimated at 39.38 cm TL and 0.38 per year, while the Tmax and theoretical age(t0) were worked out as 7.89 years and -0.4 year, respectively. In palinurid lobsters, the post-puerulus was known as the age 0 [47]. The puerulus is a transitionary stage within the spiny lobster life cycle, intermediate between the phyllosoma larva and the juvenile lobster as reported by [48].

The growth rate was reported in a few spiny lobsters of the genus *Panulirus* [49,47,50]. For example, the growth of *P. homarus* in Arabia sea was fast [51] while in Central Java and West Aceh, it grows slowly [52,53]. The value of K of *P. regius* caught in the Gulf of Guinea was similar to the K value (0.44 per year) of *P. versicolor* from the Sikka waters [54]. This K value was high compared to the value recorded in *P. penicillatus* from Central Java [55] and *P. elephas* in Tunisian waters [47]. The value K of *P. regius* recorded in here was less than 1 [56]. This indicates that the growth of this species is slow. It needs much more time to grow for reaching the commercial size standard of consumption [50].

Our findings showed that the spiny lobster *P. regius* was underexploited in the Gulf of Guinea (E < 0.5). Tthe mortality rates Z, M and F computed for this species were estimated at 1.42, 0.89 and 0.53 per year, respectively. The mortality was mainly due to natural mortality (M). Fishing mortality from spiny lobster is much lower than natural mortality [57]. Natural mortality is caused by several factors including predation, disease, food availability, physical chemical of waters. This natural mortality is also related to ecosystems, the same species in different waters may have different mortality rates depending on the density of predator and competitors [57]. The M/K ratio because this ratio reported to be within the range of 1.12-2.50 for most species [58,59]. Our findings showed that *P. regius* is recruited every month throughout the year. However, the major peak of recruitment occurred in February during the minor upwelling with recruitment strength of 15.71% and the low recruitment level (< 0.31%) was observed in August during the major upwelling period. For this species, the length of the first capture (Lc or L50) was found to be 14.04 cm TL. This size was low compared to size of first sexual maturity (SL_{50}) of 19.70 for females and 17.80 for male, indicating that *P. regius* is underexploited in the study area. The Y'/R increased with an increase in length and the maximum Y'/R appeared at a value of exploitation rate E_{max} = 0.62, which is higher than the current exploitation rate E_{est} = 0.38. The current relative yield per recruit (Y'/R) was estimated at 0.005 g per recruit while the current relative biomass (B'/R) was computed as 0.009 g per recruit. The analysis of virtual populations showed that natural mortality is high in juvenile *P. regius* and decreases as the length has increased. Fishing mortality (1.9/year) is more pronounced in adult specimens with a length of 19.5 cm TL. Individuals with sizes varying from 25.5 to 31.5 and 31.5 to 37.5 cm TL showed low fishing mortality with values of 0.4 and 0.6 $year^{-1}$, respectively.

5. CONCLUSION

In summary, the present study has provided the first results on the growth and exploitation parameters of the spiny lobster *P. regius* in the Gulf of Guinea. A unimodal TL distribution was observed with a modal TL class of 15-18 cm for each sex for this species. The size of sexual maturity was 17.80 cm for male and 19.70 cm TL for female *P. regius*. The recruitment occurred in February during the minor upwelling. Male *P. regius* attains sexual maturity earlier than female individual. The minimum legal size of 21 cm total length could be applied to protect more this species. Our data will be useful for the sustainable management of spiny fisheries.

6. REFERENCES

[1] Briones-Fourzán P. Differences in life-history and ecological traits between co-occurring *Panulirus* spiny lobsters (Decapoda, Palinuridae). ZooKeys 457, 289–311,2014. http://dx.doi.org/10.3897/zookeys.457.6669

[2] George R. Comparative morphology and evolution of the reproductive structures in spiny lobsters, *Panulirus*. New Zealand Journal of Marine and Freshwater Research 39, 493–501,1995. doi : 10.1080/00288330.2005.9517328

[3] Waiho K, Fazhan H, Shu-Chien A, Abualreesh M, Ma H, Syahnon M, Azmie G, Razman N, Ikhwanuddin M. Size distribution, length-weight relationship, and size at morphometric maturity of the Mud Spiny Lobster *Panulirus polyphagus* (Herbst, 1793) in the Johor Strait. Frontiers in Marine Science 8, 766038,2021. doi: 10.3389/fmars.2021.766038

[4] George R, Main A. L'évolution des langoustes (Palinuridae): une étude de l'évolution dans le milieu marin. Evolution 21, 803-820,1967. doi: 10.2307/2406775

[5] Froglia C, Silvestri R, Serena F. First record of *Panulirus regius* (Decapoda: Palinuridae) in the Italian seas, with remarks on the earlier Mediterranean records. Marine Biodiversity Records 5, 1- 4,2012. https://doi.org/10.1017/S1755267211000960

[6] Reddy M, Macdonald A, Groeneveld J, Schleyer MH. Phylogeography of the scalloped spiny-lobster *Panulirus homarus rubellus* in the southwest Indian Ocean. Journal of Crustacean Biology, 34, 773-781,2014.

[7] Beni Z, Wardiatno Y. Biological aspect of double-spined rock lobster (*Panulirus penicillatus*) in Wonogiri Regency waters, Central Java, Indonesia. IOP Conference Series: Earth and Environmental Science 420, 012006,2020. doi:10.1088/1755-1315/420/1/012006

[8] Situmorang Y, Sharifuddin B, Tresnati J. Carapace length-body weight relationship and condition factor of painted rock lobster *Panulirus versicolor* in Sorong waters, West Papua, Indonesia. AACL Bioflux, 14(1), 519-535, 2021.

[9] Kampouris T, Asimaki A, Klaoudatos D, Exadactylos A, Karapanagiotidis I, Batjakas I. Nutritional quality of the European spiny lobster *Palinurus elephas* (J.C. Fabricius, 1787) (Achelata, Palinuridae) and the non-indigenous northern Brown shrimp *Penaeus aztecus* Ives, 1891 (Dendrobranchiata, Penaeidae). Foods 10, 2480,2021. https://doi.org/10.3390/

[10] Clotilde-Ba F, Diatta Y, Niamadio I, Capape C. First records of the giant tiger prawn, *Penaeus monodon (Penaeus) Fabricius*, 1798. (Crustacea: Penaeidae) in the marine waters of Senegal. Bocagiana 185: 1-7,1997.

[11] Fischer W, Bianchi G, Scott W. FAO Species identification sheets for fishery purposes. Volumes VI. Eastern Central Atlantic Fishing area 34 and part of 47. FAO, Rome, Italy, 1981.

[12] Holthuis L. Marine lobsters of the world: An annotated and illustrated catalogue of species of interest to fisheries known to date. FAO Fisheries Synopsis 125, 1-292, 1991.

[13] Freitas R, Medina A, Correia S, Castro M. Reproductive biology of spiny lobster *Panulirus regius* from the northwestern Cape Verde Islands. African Journal of Marine Science 29, 201-208, 2007. Doi: 10.2989/AJMS.2007.29.2.5.188

[14] Maigret J. Contribution à l'étude de la Langouste verte de la côte occidentale d'Afrique. Thèse de Doctorat ès-Sciences Naturelles. Université d'Aix-Marseille, 264 p, 1978.

[15] Dia M, Kamara A, SOW A, Ba S. Biométrie et Éléments de Biologie de la Langouste verte (*Panulirus regius*, De Brito Capello, 1864) des côtes de Nouadhibou (Mauritanie). Bulletin de la Société Zoologique de France 140(1), 61-77, 2015.

[16] Marchal E, Barro M. Contribution à l'étude de la langouste verte africaine *Panulirus rissoni* Desmarest 1825 (*P. regius* De Brito Capello). Cahiers de l'ORSTOM, série Océanographie, **2** (3), 57-69,1964.

[17] Konan A, Etchian O, Kouamé K, Yapi J-N, Loukou G, Kadjo V. Typologie de la pêche de la langouste verte *Panulirus regius*, De Brito Capello, 1864 sur le littoral de la Côte d'Ivoire (Afrique de l'Ouest). International Journal of Biological and Chemical Sciences 15(4), 1573–1580,2021. DOI : https://dx.doi.org/10.4314/ijbcs.v15i4.21

[18] Moruf R, Afalaya O, Taiwo M, Ogunbambo M. Estimation of nutritional energy values, mineral ratio and mineral safety index in the Royal spiny lobster, *Panulirus regius* (De Brito Capello, 1864). Croatian Journal of Food Science and Technology 13(1), 105-110, 2021. doi: 10.17508/CJFST.2021.13.1.13.

[19] Peixoto U, Mesquita E, Cintra I, Klautau A, Gouveia N, Paes E, Isaa V. Population dynamics and sustainability of the spiny lobster (*Panulirus meripurpuratus* Giraldes & Smyth, 2016) fishery on the Amazon continental shelf. Marine and Freshwater Research 72, 99-109, 2020. https://doi.org/10.1071/MF19333.

[20] Binet D, Marchal E. The large marine ecosystem of shelf areas in the Gulf of Guinea: long-term variability induced by climatic changes. In: Large marine ecosystems: stocks, mitigation and sustainability (Shermon K, Alexander L. M, Gold B. D. eds.), pp. 104-118, 1993.

[21] Koranteng K, McGlade J. Climatic trends in continental shelf waters off Ghana and in the Gulf of Guinea, 1963-1992. Oceanologica Acta 24 : 187-198, 2001. https://doi.org/10.1016/S0399-1784(01)01140-9.

[22] Schneider W. FAO Species Identification Guide. Guide to the marine commercial resources of the Gulf of Guinea. FAO, RAFR / FI / 90 / 2. Rome, 268 pp,1992.

[23] Scherrer B. Résultats des données. In Biostatique, Gaetan, Morin (eds). Louiseville : Canada ; 850 p,1984.

[24] Gayanilo F, Sparre P, Pauly D. The FAO-ICLARM Stock Assessment Tools (FISAT) User's Guide. FAO Computerized Information Series (Fisheries), 128p,1996.

[25] Loukou A, Sylla S, Etchian A, Konan A, Atsé A. Growth and exploitation parameters of the West African ladyfish *Elops lacerta* Valenciennes, 1847 in the Ivorian's exclusive economic zone, Côte d'Ivoire. International Journal of Aquatic Biology 9(6), 360-369, 2021.

[26] Gayanilo F, Sparre P, Pauly D. FAOICLARM Stock Assessment Tools II (FiSAT II). Revised. User's guide. FAO Computerized Information Series (Fisheries), Rome, 8: 168 p, 2005.

[27] Von Bertalanffy L. A quantitative theory of organic growth (inquiries on growth laws II). Human Biology, 10(2), 181-213,1938.

[28] Pauly D. Une sélection de méthodes simples pour l'estimation des stocks de poissons tropicaux. FAO Circ. Pêches, (729), 63 p,1982.

[29] Pauly D. Fish population dynamics in tropical waters: A manual for use with programmable calculators. ICLARM studies and reviews, 8, 325 p,1984. International Center for Living Aquatic Resources Management, Manila, Philippine.

[30] Pauly D, Munro J. Once more on the comparison of growth in fish and invertebrates, Fishbytes, the WorldFish Center 2(1), 1-21,1984.

[31] Gulland J. The Fish Resources of the Ocean. West Byfleet, Surrey, Fishing News (Books) Ltd., for FAO: West Byfleet, Rome, 255 pp,1971.

[32] Pauly D. Some simple methods for the assessment of tropical fish stocks. FAO Fish. Tech. Pap. (234), 52 p, 1983.

[33] Sparre P, Venema SC. Introduction to tropical fish stock assessment, Part I: Manual. FAO Fisheries Technical Paper, 306(1), 1-376 p,1998.

[34] Asrial E, Rosadi E, Hamid-Ichsan M, Khasanah R, Sulystyaningsih N, Sumiwi A, Khalisah N. Growth and population parameters of *Panulirus penicillatus* and *Panulirus homarus* in Labangka tidal Waters, Indonesia. Jurnal Ilmiah Perikanan dan Kelautan 12(2), 214-223, 2020. http://doi.org/10.20473/jipk.v12i2.21486.

[35] Beverton R, Holt S. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapports et procès-verbaux des réunions. Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée, 140, 67-83,1956.

[36] Pauly D, Soriano ML. Some practical extensions to Beverton and Holt's relative yield-per recruit model. In: J.L. Maclean, L.B. Dixin, L.V. Hosillo (Eds.), First Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines, pp: 491-496, 1986.

[37] Beverton R. Patterns of reproductive strategy parameters in some marine teleost fishes. Journal of Fish Biology, 41: 137-160,1992.

[38] Caill-Milly N, Sanchez F, Benito D, Ruiz P, Izagirre U, Briaudeau T. Assessment of size at first maturity for *Ruditapes philippinarum* from Arcachon Bay (French Atlantic coast): New insights for fishery management. Estuarine, Coastal and Shelf Science, 285, 108321,2023. https://doi.org/10.1016/j.ecss.2023.108321

[39] Ghorbel M, Jarboui O, Bradai M, Bouain A. Détermination de la taille de la première maturité sexuelle par une fonction logistique chez *Limanda limanda*, *Pagellus erythrinus* et *Scorpaena porcus*. Bulletin de Institut National Scientifique et Technique d'Océanographie et de Pêche de Salammbô 3, 24-27, 1996.

[40] Goñi R, Latrouite D. Review of the biology, ecology and fisheries of *Palinurus* spp. species of European waters: *Palinurus elephas* (Fabricius, 1787) and *Palinurus mauritanicus* (Gruvel, 1911). Les Cahiers de Biologie Marine 46, 127-142, 2005.

[41] Follesa M, Cuccu D, Cannas R., Cabiddu R, Murenu M, Sabatini A, Cau A. Effect of marine reserve protection on spiny lobster (*Palinurus elephas Fabr*., 1787) in a central western Mediterranean area. Hydrobiologia, 606, 63-68, 2008.

[42] Kizhakudan J, Patel SK. Size at maturity in the mud spiny *lobster Panulirus polyphagus* (Herbst, 1793) Journal of Marine Biological Association of India, 52(2), 170-179, 2010.

[43] Thangaraja R, Radhakrishnan EV. Reproductive biology and size at onset of sexual maturity of the spiny lobster *Panulirus homarus homarus* (Linnaeus, 1758) in Khadiyapatnam, southwest coast of India. Journal of Marine Biological Association of India, 59(2), 19-28, 2017.

[44] Crosnier A. Ponte et développement larvaire de la langouste verte *Panulirus regius* de Britto Capello, 1864 dans le sud du Golfe de Guinée. Cahier ORSTOM, série Océanographie, 9 (3), 339-361, 1971.

[45] Butler M, Bertelsen R, MacDiarmid A. Mate choice in temperate and tropical spiny lobsters with contrasting reproductive systems. ICES *Journal of Marine Science*, 72, 101-114, 2015. doi:10.1093/icesjms/fsu22

[46] Baisre J, Pérez A, Obregón MH, Cruz R. Regulation of fishing effort on Cuban shelf fisheries: the case studies of shrimp, lane snapper and spiny lobster fisheries. FAO Fish Rep. 298 Suppl. 3:365-390, 1983..

[47] Rjeibi O, Gaamour A, Missaoui H. Etude de la croissance de la langouste rouge « *Palinurus Elephas* », dans les eaux Tunisiennes. Bulletin de l'Institut National des Sciences et Technologies de la Mer, 38, 41-54,2011.

[48] Priyambodo B, Jones C, Sammut J. Assessment of the lobster puerulus (*Panulirus homarus* and *Panulirus ornatus*, Decapoda: Palinuridae) resource of Indonesia and its potential for sustainable harvest for aquaculture. Aquaculture, 528, 735563, 2020. https://doi.org/10.1016/j.aquaculture.2020.735563.

[49] Leocádio A, Cruz R. Growth parameters of the spiny lobster (*Panuliris argus)* in the great caribbean : A review. Rev. Invest. Mar., 29(3), 239-248, 2008.

[50] Larasati R, Suadi S, Setyobudi E. Short communication: Population dynamics of double-spined rock lobster (*Panulirus penicillatus* olivier, 1791) in southern coast of Yogyakarta, Indonesia. Biodiversitas 19(1), 337-342, 2018.

[51] Mehanna S, Al-Shijibi S, Al-Jafary J, Al-Senaidi R. Population dynamics and management of scalloped spiny lobster. *Journal of Biology*, Agriculture and Healthcare 2: 184-194,2012.

[52] Bakhtiar NM, Solichin A, Saputra SW. Growth and mortality rate of Green scalloped rock lobster in Cilacap waters of Central Java. Diponegoro J Maquares 2, 1-10, 2013.

[53] Kembaren D, Nurdin E. Distribution of the size and parameters of the population of Green scalloped rock lobster (*Panulirus homarus*) in the waters of West Aceh. J Bawal 7: 121-128, 2015.

[54] Ernawati T, Suprapto DDK, Sumiono B. Parameters of Painted rock lobster population (*Panulirus versicolor*) in North Waters of Sikka Regency and surrounding areas. J Bawal 6: 169-175, 2014.

[55] Zaenuddin M, Putri D. Size distribution of rock lobster (*Panulirus penicillatus*) in Wonogiri Waters of Central Java. Saintek Perikanan 12, 109-115, 2017.

[56] Sparre P, Venema SC. Introduction of tropical fish stock assessment, Book 1: Manual. Center for Fisheries Research and Development. Jakarta. 438 pp,1999.

[57] Irwani, Sabdono A, Wijayanti D P. Growth, Mortality and Exploitation Rate of Spiny Lobster (*Panulirus Homarus*) from Kebumen and Cilacap Coastal. 4th International Conference on Tropical and Coastal Region Eco Development IOP Conf. Series: Earth and Environmental Science 246, 012081,2019.IOP Publishing doi:10.1088/1755-1315/246/1/012081.

[58] Beverton RJ, Holt S. On the dynamic of exploited fish populations. Great Britain Fishery Investigations, 19 (2), 533 pp,1957.

[59] Panda D, Chakraborty S, Jaiswar K, Sharma A, JHA B, Bahgabati K, Kumar T. Fishery and population dynamics of two species of carangids, *Decapterus russelli* (Ruppell,1830) and *Megalaspis cordyla* (Linnaeus,1758) from Mumbai waters. India J. Fish.,59(4), 53-60,2012.