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Original Article

Reproductive biology of the Guinean amberjack, *Seriola carpenteri* (Mather, 1971) in the exclusive economic zone (EEZ) of Côte d'Ivoire

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Abstract: The reproduction of *Seriola carpenteri* (Mather, 1971) was studied from August 2017 to July 2018 in the Ivorian Exclusive Economic Zone (EEZ) based on samples from artisanal fishing at the Abobo-Doumé canoe dock. A total of 360 specimens, including 197 males and 163 females, were examined. The sex ratio is 1:1. The monthly monitoring of the Gonado-Somatic Index (GSI) and the stages of sexual maturity revealed that *S. carpenteri* reproduces twice a year in all seasons. The first period extends from September to January, and the second runs from March to June. The Hepato-Somatic Index (HSI) indicates that *S. carpenteri* is a lean fish. The size of the first sexual maturity (L_{50}) of the *S. carpenteri* population is 30.43 cm, with males reaching 30.77 cm and females 30.05 cm. Absolute fecundity varies from 27,750 to 225,330 oocytes for weights ranging from 300.2 to 935 g, with standard lengths ranging from 22.8 to 36.2 cm. Relative fecundity ranges between 68 and 254 oocytes per gram of body weight. *Seriola carpenteri* exhibits high reproductive success due to its low atresia rate of 19.32%. The database formed by the results of this study could serve as a basis for the domestication of this species in the marine ecosystem, aiming for greater availability of animal protein and rational exploitation of this fishery resource.

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Introduction

Reproduction is a crucial stage in the life cycle of a fish. The demographic balance of a fish species is closely linked to the proper progression of this phase (Parkinson et al., 1999). The Guinean amberjack, *Seriola carpenteri* (Mather, 1971), is a species belonging to the Carangidae family. The Guinean amberjack is primarily found along the West African coasts and in the Mediterranean (Golani et al., 2002). *Seriola carpenteri*, present in Côte d'Ivoire within the Exclusive Economic Zone (EEZ), is caught alongside species from the Thonidae family. Studies on the morphological characteristics of this species have been conducted in the North-East Atlantic (Quéro, 1986), in the Mediterranean (Louisy, 2015), as well as in northeastern Tunisia and off the Senegalese coast (Capapé et al., 2018). In marine areas such as Lampedusa Island in the Mediterranean, studies have been conducted on the reproduction of this species (Pizzicori et al., 2000).

This species is increasingly abundant in catches, especially in artisanal fisheries, and is becoming a staple in the dietary habits of Ivorian populations. Despite its growing economic importance, this species lacks scientific data on its biology and ecology in the Central-Eastern Atlantic, particularly in Côte d'Ivoire. To assess the viability of any aquaculture, the factors to consider are the diet and reproductive strategy. It is, therefore, necessary to ensure the survival and sustainability of the stock in its natural environment by initiating investigations to understand the various factors controlling the proliferation of this species. Furthermore, for the rational management of fish stocks, it is crucial to know the reproductive parameters of fish species, including the size at first sexual maturity, fecundity, and breeding period (Khao et al., 1999; Offem et al., 2009). This study aims to determine the reproductive parameters of

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S. carpenteri within the Ivorian EEZ by understanding its sex ratio, size at first sexual maturity, breeding period, and fecundity. This study contributes to obtaining basic biological and ecological data on *S. carpenteri* for its domestication in the marine ecosystem.

Materials and Methods

Study Area: This study was conducted within the Exclusive Economic Zone (EEZ) of Côte d'Ivoire, located in the Gulf of Guinea (Atlantic Ocean). The Ivorian EEZ extends from Cape Palmas (8°W) in the west to Cape Three Points (2°30'W) in the east (Diaha et al., 2010), covering a coastline length of approximately 600 kilometers (Fig. 1). It is characterized by significant variability in climatological parameters (winds, and precipitation) and oceanographic conditions (temperature, salinity, mean sea level, dissolved oxygen, and currents) (N'Goran et al., 2001). Sea surface salinity is influenced by the intensity of freshwater inputs and precipitation (Gougnon et al., 2018). This study obtained sea surface temperature (SST) from August 2017 to July 2018 from NASA's database using the MODIS (Moderate Resolution Imaging Spectroradiometer) satellite. The extracted data were processed using NASA's SeaDAS (SEAWIFS Data Analysis System) software, where they were geometrically corrected by applying the coordinates of the study area (Djagoua et al., 2011).

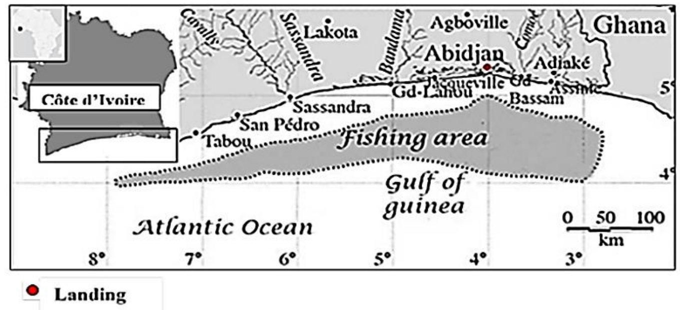

Figure 1. Artisanal fishing zone in Côte d'Ivoire.

Sampling and Data Analysis: A monthly sampling of artisanal commercial fish landings in Abobo-Doumé was conducted from August 2017 to July 2018. *Seriola carpenteri* specimens were obtained from the pirogue quay in Abobo-Doumé, Abidjan, from artisanal fishermen operating within the EEZ. Once a month, 30 specimens were collected and quickly transported to the laboratory at the Oceanological Research Center (CRO) in Abidjan. A total of 360 specimens, including 197 males and 163 females, were collected from August 2017 to July 2018. For each specimen, the standard and total lengths were recorded to the nearest millimeter, and the total weight and eviscerated weight to the nearest gram. Each individual was dissected, and the gonads and livers were removed and weighed to the nearest gram.

Gonad maturity stages: The sex and sexual maturity stages of the sampled fish were determined using the macroscopic maturity scales of Fontana (1969). The six macroscopic stages of gonad maturity for both sexes, according to Kouamé et al. (2018), are as follows: Stage I (immature); Stage II (immature); Stage III (developing); Stage IV (developed/pre-spawning); Stage V (spawning); Stage VI (post-spawning).

Sex ratio: The sex ratio (SR), expressing the relative proportion of males and females in a population at a given time, was determined using the formula (Kartas and Quignard, 1984) of $SR = (M / F) \times 100,$ where M = males and F = females.

Gonado-somatic and Hepato-Somatic indices: To establish the sexual cycle and determine the spawning period, the Gonado-Somatic Index (GSI) and the Hepato-Somatic Index (HSI) were calculated monthly using the formulas (Amira et al., 2019) of $GSI = (Wg / We) \times 100$, and $HSI = (Wf / We) \times 100,$ where Wg = gonad weight (g), Wf = liver weight (g), and We = eviscerated weight (g).

Size at first sexual maturity: The size at first sexual maturity for males and females (LS_{50}) was determined using the fork length of mature individuals (stages iii, iv, v, and vi). Individuals were grouped by size class, and the percentage of mature individuals in each size class was calculated. Excel was used to determine the value of the equation (ln(P)/(1-P)) for each size class. Linear regression of the equation (y=aX-b) was used to determine the values of the constants a and b

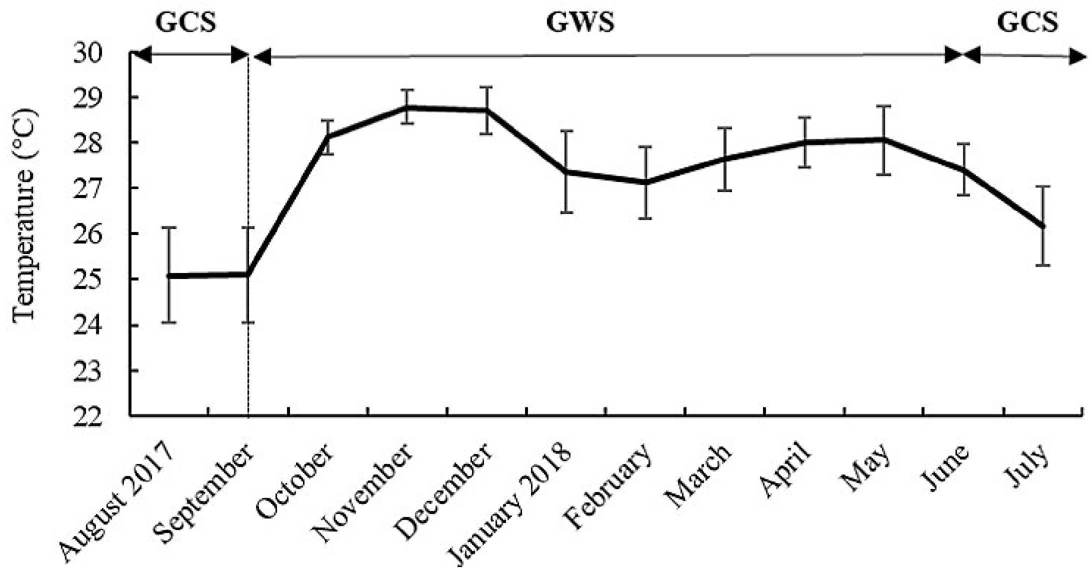

Figure 2. Monthly average evolution of sea surface temperature in the Exclusive Economic Zone from August 2017 to July 2018 (GCS: Great Cold Season; GWS: Great Warm Season).

(Ghorbel et al., 1996). The chi-square test (X^2) was used to compare the sex ratio percentages for different months and seasons with the theoretical sex ratio (1:1). The estimation of the size at first sexual maturity (LS50) was established by fitting a logistic function using nonlinear regression to the percentages of mature individuals by size class interval (Konan et al., 2013). The proportion of mature fish per size class and size at first sexual maturity were calculated using $P = (1 / (1 + e\text{^-}(a + b*Ls))) \times 100$ and $LS_{50} = -a/b$, where P = Proportion of mature fish per size class, LS = Standard length, and a and b = constants.

Fecundity and oocyte atresia: Absolute fecundity (number of oocytes in an ovary) and relative fecundity (number of oocytes per unit of body weight) (Kartas and Quignard, 1984) were evaluated to determine reproductive potential. Oocyte atresia (number of atretic oocytes relative to the total number of oocytes) was also assessed to determine reproductive success in this species (Murua and Motos, 2006).

Results

Sea surface temperature: The average sea surface temperature across different marine seasons from August 2017 to July 2018 was estimated in this study (Fig. 2). The highest average temperature was recorded in November (28.79±0.38°C), while the lowest was observed in August (25.09±1.04°C). Analysis of the temperature trends revealed two marine seasons: a long cold season (temperature ≤ 27°C) from July to September, and a long warm season (temperature > 27°C) from October to June. During this period, the temperature in the cold season ranged from 25.09 to 26.18°C, while the temperature in the warm season ranged from 27.13 to 28.79°C. Variance analysis between the cold and warm seasons showed a significant difference between these two marine seasons (P<0.05).

Gonad maturity stages: The proportions of sexual maturity stages observed in females and males throughout the study period (Fig. 3). Six sexual stages were recorded, but in varying proportions. In females, the proportion of stage I specimens was high in January, reaching 63.63%. The lowest proportions of individuals in this stage were recorded in October (8.33%) and April (8.33%). In contrast, no stage I individuals were found in November. Stage II individuals were absent in March and June, with the highest proportion observed in September (46.66%). The lowest proportions of stage II specimens were recorded in November (8.33%) and May (8.33%). Stage III fish were present every month during the sampling period, with the highest proportion in April (41.66%) and the lowest in January (4.54%). Stage IV specimens were absent from the July sample, with the highest proportions observed in October (50%) and

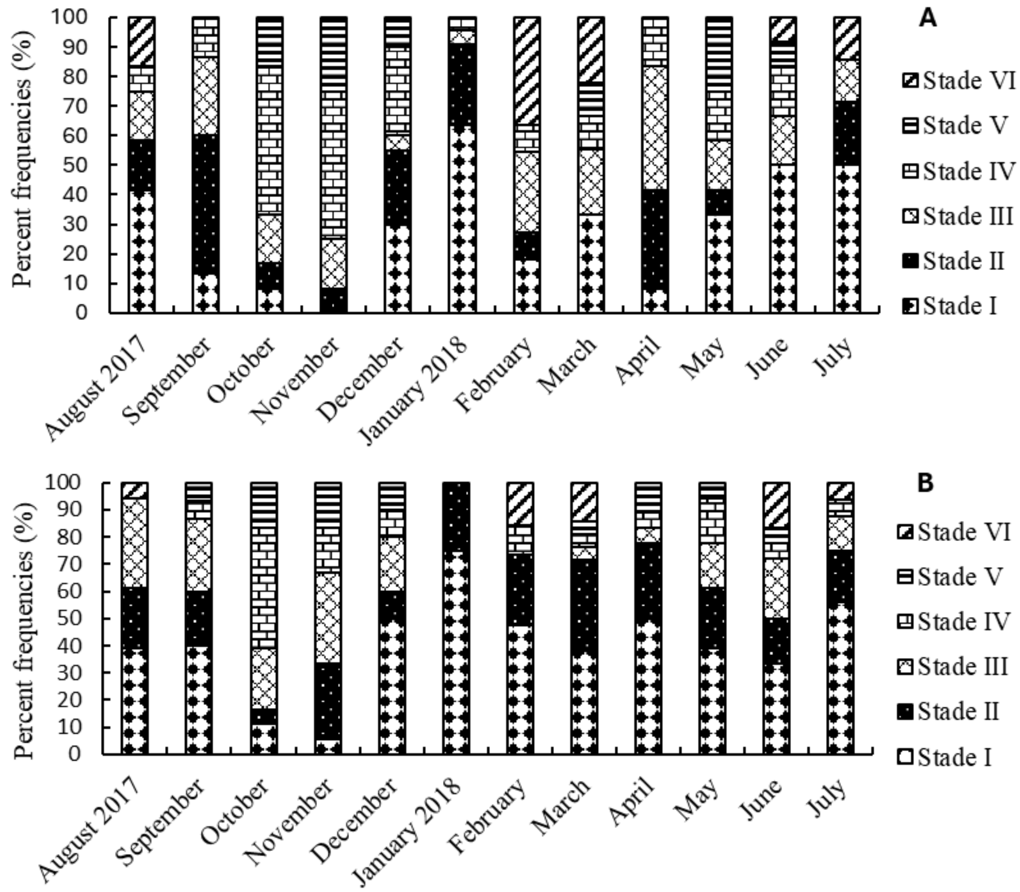

Figure 3. Monthly variation in the sexual maturity stages of female (A) and male (B) *Seriola carpenteri* captured in the Ivorian EEZ from August 2017 to July 2018.

November (50%). Stage V individuals were absent in the August, September, January, February, April, and July samples. The highest proportions of stage V individuals were found in November and May (25%), while the lowest was in June (8.33%). Post-spawning stage (stage VI) individuals were absent in the samples from September to January and April to May. The highest proportion of stage VI specimens was observed in February (36.36%), and the lowest in June (8.33%) (Fig. 3A).

In males, the highest proportions of stage I specimens were observed in January (75%), July (56%), and April (50%), while the lowest proportion was recorded in November (5.55%). Stage II specimens were abundant in March (33.33%) and sparsely represented in October (5.55%). Stage III specimens were absent in January and February, with the highest proportion in November (33.33%) and August (33.33%), and the lowest in March (4.76%). Stage IV specimens were absent from the August and January samples, with the highest proportion in October (44.44%) and the lowest in March (4.76%). Stage V individuals were absent in the August, January, February, and July samples. A high proportion of stage V individuals was noted in October (16.66%), with a low proportion in March (4.76%). Finally, stage VI individuals were present in the August, February, March, June, and July samples, with the highest proportion in June (16.66%) and the lowest in August (5.55%) (Fig. 3B).

Sex ratio: A total of 360 *S. carpenteri* were sampled at the Abobo-Doumé dock. Of the entire fish, 163 were females (45.28%) compared to 197 males (54.72%). Although there were more males than females, the chi-square test showed no significant difference between the two sexes ($\chi^2 = 3.21$; $P=0.07$) (Table I). The overall sex ratio (1:1.23) was not significantly different from the theoretical sex ratio.

Table 1. Monthly variation of the sex ratio of the *Seriola carpenteri* population fished in the Ivorian EEZ from August 2017 to July 2018.

Months	Female count	Male count	Total count	Sex-ratio (M: F)	χ^2	*P-Value*
August 2017	12	18	30	1:1.50	1.20	0.27
September	15	15	30	1:1.00	0.00	1.00
October	12	18	30	1:1.50	1.20	0.27
November	12	18	30	1:1.50	3.33	0.27
December	20	10	30	1:0.50	3.33	0.06
January 2018	22	08	30	1:0.36	6.53	0.01*
February	11	19	30	1:1.72	2.13	0.14
March	09	21	30	1:2.33	4.80	0.02*
April	12	18	30	1:1.50	1.20	0.27
March	12	18	30	1:1.50	1.20	0.27
June	12	18	30	1:1.50	1.20	0.27
July	14	16	30	1:1.14	0.13	0.71
Cold season	98	112	210	1:1.14	0.93	0.33
Warm season	65	85	150	1:1.30	2.66	0.10
Total	163	197	360	1:1.23	3.21	0.07

Theoretical χ^2 = 3.84; probability threshold 5%; significant (*); F = Female; M = Male.

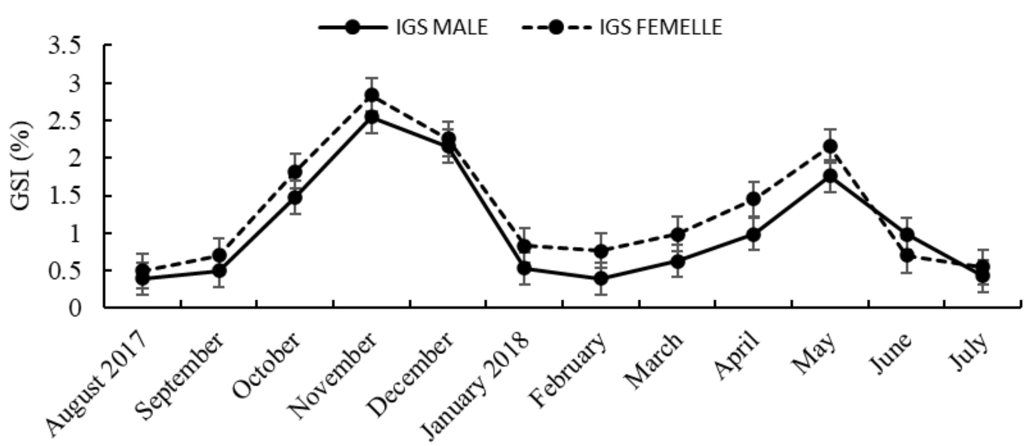

Figure 4. Monthly variation of the Gonado-Somatic Index (GSI) in female and male *Seriola carpenteri* captured in the Ivorian EEZ from August 2017 to July 2018.

Similarly, the monthly variation in the sex ratio showed no significant difference from the theoretical sex ratio of 1:1 throughout the year, except in January, where females were significantly more numerous than males (χ^2 = 6.53; *P*=0.01), and in March, which recorded a dominance of males (χ^2 = 4.8; *P*=0.02). Seasonally, males outnumbered females. However, chi-square tests for the cold season (χ^2 = 0.93; *P*=0.33) and the hot season (χ^2 = 2.66; *P*=0.10) did not show a significant difference from the theoretical sex ratio (1:1).

Gonado-Somatic index and reproductive period: The analysis of gonad weight throughout the year helped identify the reproductive period of *S. carpenteri*. The Student's t-test between the mean GSI (Gonado-Somatic Index) of females (1.30±0.67) and males (1.07±0.61) showed no significant difference (*P*=0.12). The mean GSI of both males and females follows a similar trend. The monthly variations in GSI for females and males reveal two peaks for each sex (Fig. 4). In males, the GSI reaches its highest value in November (2.54±0.85). The second peak is lower than the first and occurs in May (1.75±0.73). The lowest values are observed in August (0.39±0.3). The analysis of the GSI curve indicates two reproductive periods for *S. carpenteri*. The first period extends from September to January during the cold marine season, with the first spawning period from November to January during the hot marine season. The second reproductive period extends from March to June

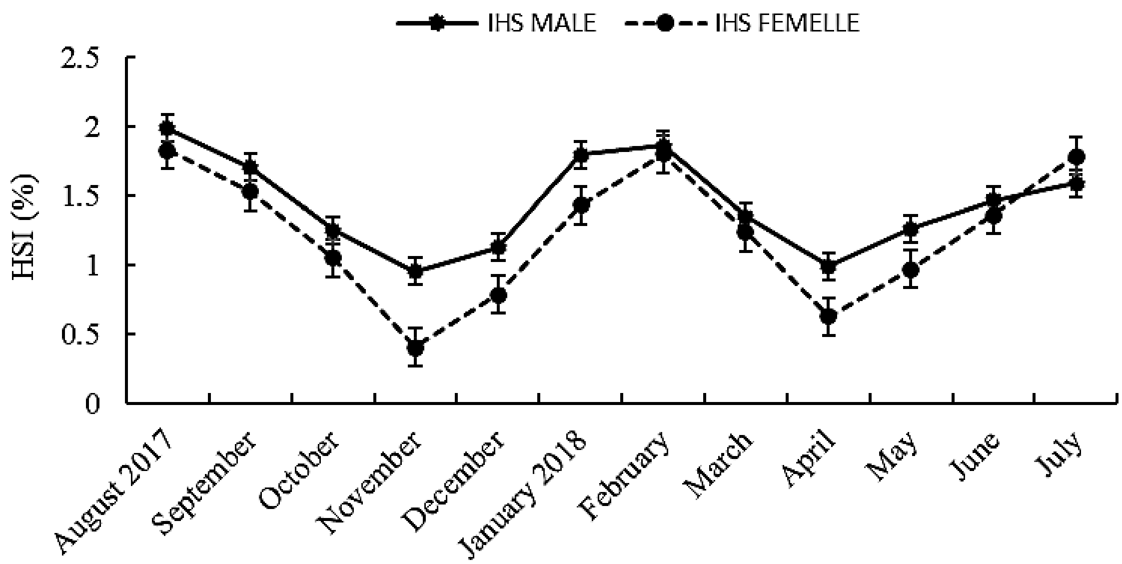

Figure 5. Monthly variation of the Hepato-Somatic Index (HIS) in female and male *Seriola carpenteri* caught in the Ivorian EEZ from August 2017 to July 2018.

during the hot marine season, with the second spawning period occurring from May to June during the cold marine season.

Hepato-Somatic index: Similar trends were observed in the mean Hepato-Somatic Index (HSI) of both sexes (Fig. 5). The Student's t-test between the mean HSI of females (1.23±0.39) and males (1.44±0.29) showed no significant difference ($P>0.05$). HSI values increased from November to February and from May to August, with two peaks in August (1.98±0.15 and 1.82±0.14 for males and females, respectively) and in February (1.85±0.32 and 1.79±0.22 for males and females, respectively).

Size at first sexual maturity: In *S. carpenteri* population in the Ivorian EEZ, sexual maturity is reached at 30.43 cm (Fig. 6A). In females, sexual maturity is reached at 30.05 cm (Fig. 6B), while in males, it is reached at 30.77 cm (Fig. 6C). The Chi-square test applied to these values did not show any significant difference ($\chi^2 = 0.1$; $P=0.910$). The smallest mature individuals were 29.9 cm for females and 30.6 cm for males.

Fertility and oocyte atresia: The absolute fecundity of females, or the number of oocytes per ovary, ranged from 27,750 to 225,330 oocytes, with an average value of 103,702±6,696 oocytes for females measuring between 29.9 and 35.8 cm in size and weighing between 408.08 g and 887.12 g. The relative fecundity varied from 68 to 254 oocytes per gram of body weight, averaging 121±23 oocytes. The atresia rate was 19.32%.

Discussions

The two major marine seasons (a long warm marine season and a long cold marine season) observed in this study, instead of four, can be explained by the effects of climate change on the marine environment, which are leading to changes in ocean surface temperatures and consequently reducing the number of marine seasons. The rapid increase in greenhouse gases in the atmosphere causes heat accumulation in the climate system. As a result, the existence of four marine seasons at the sea surface is no longer relevant. Even though the work conducted by Tia (2020) mentions the existence of four marine seasons, it is a mistake in analysis and interpretation. This author merely used the division previously made by Mahan et al. (2008) instead of analyzing satellite data highlighting the presence of two marine seasons. The same applies to the work of Diaha et al. (2010). The drop in temperature during the cold seasons is explained by the intensification of upwelling, which brings cold water along the Ivorian coast. During this period, the coldest waters (with temperatures below 26°C) are found near the coast in the west (Arfi et al., 1991). Similar results were obtained by Tia (2020) and

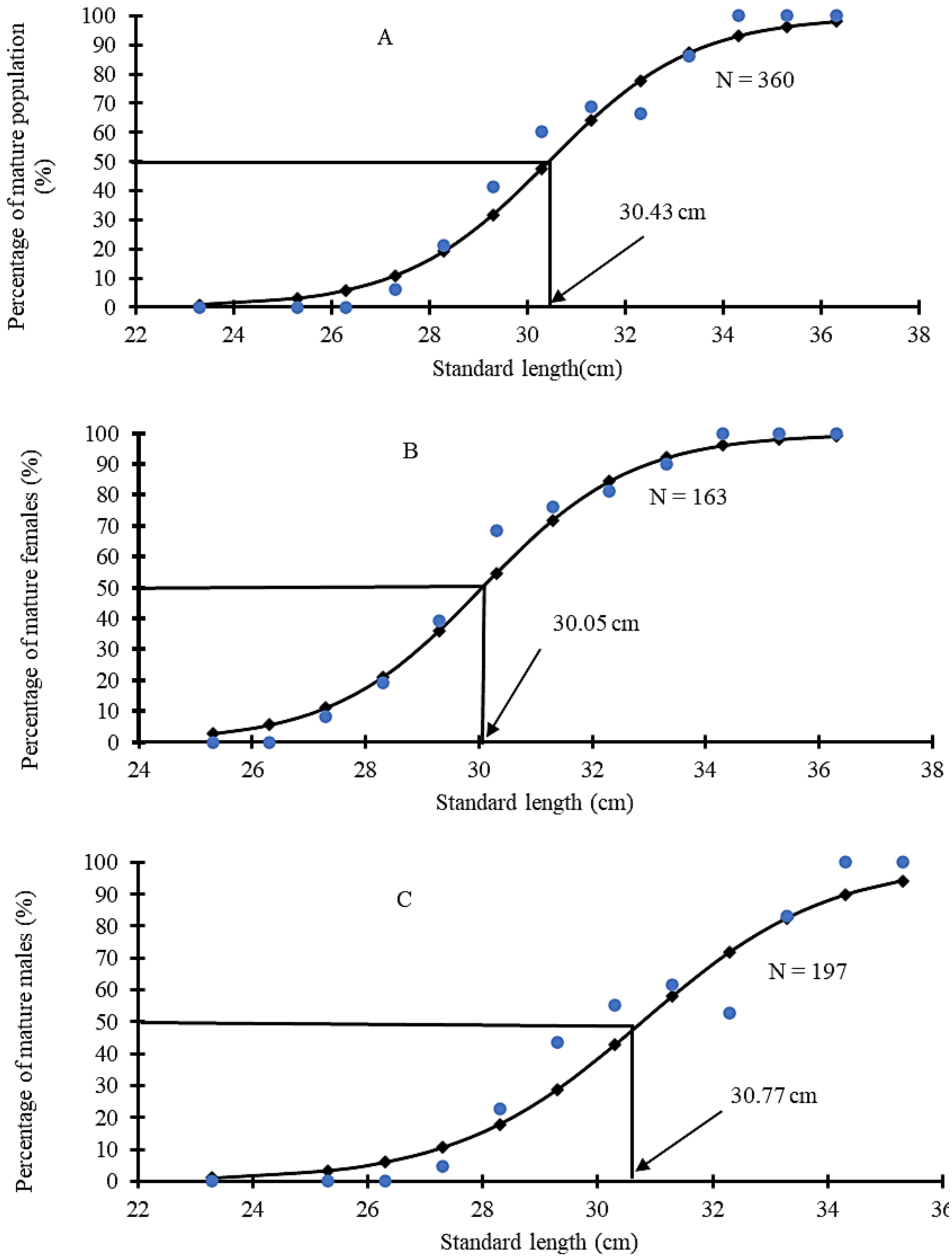

Figure 6. Curve of the determination of the size at first sexual maturity for the population (A), for mature females (B), and for mature males (C) of *Seriola carpenteri*.

Mahan et al. (2008). In contrast, during the warm marine season, the temperature of Ivorian waters is elevated, exceeding 27°C. This temperature rise coincides with the rainy season in Côte d'Ivoire, and with the contribution of major rivers, the ocean gains heat, and the sea surface temperature reaches a maximum of 28.60°C (Djagoua, 2003).

Gametogenesis in *S. carpenteri* is continuous or asynchronous because not all oocytes in the gonads reach maturity simultaneously. Several developmental stages of oocytes are present in the same ovary. Six stages of oocyte development (stages I, II, III, IV, V, and VI) were identified. The analysis of the monthly variation in sexual maturity stages shows that mature individuals (males and females) are present each month of sampling. The release of reproductive products occurs throughout the year.

Our results show that the sex ratio of *S. carpenteri* in the EEZ is similar to 1:1. No significant difference was observed in the sex ratio of all *S. carpenteri* individuals throughout the year, except in January, where the number of females was significantly higher than males, and vice versa in March. These monthly variations could be attributed to environmental conditions, food availability, sampling size, and habitat (Khallaf and Authman, 2010; Nieto et al., 2010). Factors such as feeding movements, differential growth, and sex-specific mortality rates are also considered to influence the sex ratio in fish (Mellinger, 2002). According to Aka et al. (2004), sex ratio variation depends on the physiological state of the fish. Generally, in teleost fish, males predominate during the breeding season, while females predominate during the resting season (Paugy, 1980; Santos et al., 2007). During the study period, seasonal variations showed no sex predominance during the cold or warm marine seasons. Our results are similar to those obtained by Sylla et al. (2009) in Côte d'Ivoire in the Ebrié Lagoon with *Trachinotus teraia*, a species from the same family. These authors observed a balanced sex ratio (1:1) in this species. However, our results differ from those observed by Assan et al. (2017) in the Gulf of Guinea in Côte d'Ivoire for *Elagatis bipinnulata*, a species from the Carangidae family. These authors found that females outnumbered males regardless of the time of year and the size of the individuals caught. This dominance of one sex may be related to longevity, differential catches, or the spatio-temporal distribution of the sexes (Morato et al., 2003). Furthermore, the high number of females compared to males may be an advantage for the survival of *S. carpenteri* in the Ivorian EEZ.

The monthly monitoring of the GSI is a good method for studying fish reproduction. This parameter reveals the periods of sexual activity and reproduction. The monthly monitoring of GSI revealed that *S. carpenteri* reproduces twice a year. The first period extends from September to January, and the second from March to June. Our results are consistent with those of Pizzicori et al. (2000) in the Mediterranean on Lampedusa Island for the same species. These authors showed that the reproduction of *S. carpenteri* was still detectable at the end of September and could continue after observing mature ovaries in 20 specimens captured in the same area in August. Our results also align with those of Smith-Vaniz (1986). According to this author, *S. carpenteri* reproduces in warm and cold seasons. Additionally, HSI of males and females follows the same trend. Moreover, the HSI and the GSI evolve in opposite directions. This would indicate that *S. carpenteri* is a lean fish, showing that its energy reserves accumulate mainly in the liver (Djadji et al., 2013). In this case, the reserves stored in the liver are used for gonad development; furthermore, during gonad maturation, the fish draws from its liver reserves rather than its muscles (Chemman-Abdelkader, 2002).

Determining the size at first sexual maturity in fish is essential for setting the minimum catch size (Mehanna, 2007). The size at first sexual maturity of the *S. carpenteri* population obtained in the EEZ is 30.43 cm in standard length. The sizes of first sexual maturity for *S. carpenteri* are 30.77 and 30.05 cm in standard length for males and females, respectively. A comparison of the size at first maturity between males and females of *S. carpenteri* shows no significant difference. However, females reach sexual maturity at a smaller size than males. This result would suggest that females reach sexual maturity earlier than males. Similar results were obtained by Assan et al. (2017) in the Gulf of Guinea for another species of Carangidae, *Elagatis bipinnulata*. These authors showed that females (60.33 cm) reach sexual maturity earlier than males (63.69 cm) in terms of fork length. Our results are also consistent with those of N'Guessan (2019) concerning the species *Caranx crysos*. This author reports that this species's females (26.88 cm) reach maturity earlier than males (27.73 cm). However, our results differ from those obtained by Marino et al. (1995) in the Mediterranean on *Seriola dumerili*. Marino et al. (1995) showed that males (SL = 109 cm) reached maturity earlier than females (SL = 113 cm). Our findings provide an important clue for identifying *S. carpenteri* and *S. dumerili*, given the similarity between the two species. Thus, they showed that size differences could be due to phenotypic and physiological differences between species of the same genus. In many cases, size differences are associated with sexual differences related to energy distribution for gamete production (Koné et al., 2011). Human activities such as overfishing (intensified fishing effort) may also explain these size differences. Early sexual maturity is indeed a strategy adopted by fish to increase the chances of reproduction among survivors and the possibility of stock replenishment (Sley et al., 2012).

Seriola carpenteri can be considered like a species that does not belong to the highly fecund fish family. Indeed, species with very high fecundity, such as *Trachinotus teraia*, *Mugil cephalus*, and *Pellonula leonensis*, produce millions of eggs (Sylla et al., 2009; Koné et al., 2011; Djadji et al., 2013). The oocyte atresia rate is estimated at 19.32%. This low atresia rate could be linked to stress from fishing activity, the fish's physiological state, or a lack of food in its environment (Murua and Motos, 2006). This species has a low absolute fecundity value, which reflects its low reproductive potential. However, the low atresia rate (well below 50%) places this fish among species with high reproductive success.

Conclusion

The study of some reproductive parameters of the Guinean amberjack captured in EEZ of Côte d'Ivoire by artisanal fishing, conducted from August 2017 to July 2018 at the Abobo-Doumé embarkation dock, recorded six stages of sexual maturity in both males and females, with a balanced sex ratio (1:1). The evolution of GSI and HSI showed that *S. carpenteri* reproduces twice a year in all seasons. The first sexual maturity size (LS_{50}) of the population is 30.47 cm, with males and females reaching maturity at 30.77 and 30.05 cm standard length, respectively. This species has a low absolute fecundity of 27,750 to 225,330 oocytes, with an average value of 103,702±6,696 oocytes. The rate of oocyte atresia is very low, making this fish one of the species with the highest reproductive success.

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