

REPRODUCTIVE BIOLOGY OF BARRACUDA, *SPHYRAENA GUACHANCHO*, ON IVORIAN COASTS (EASTERN CENTRAL ATLANTIC)

C. M. A. AKADJE^{1,2}, Y. N. AMON³, K. N'DA⁴, F. LE LOC'H^{5*}

¹Laboratoire des Ressources Aquatiques Vivantes, Centre de Recherches Océanologiques, BP V 14 18, Abidjan, Côte d'Ivoire

²University of Man, UFR Forestry and Environmental Agronomic Engineering, BP 20 Man, Côte d'Ivoire

³Université Peleforo Gon Coulibaly, UFR-Sciences Biologiques, BP 1328 Korhogo, Côte d'Ivoire

⁴Laboratoire de biologie cytologie animale, Université d'Abobo-Adjamé, 02 BP 801, Abidjan 16, Côte d'Ivoire

⁵IRD, Univ Brest, CNRS, Ifremer, LEMAR, IUEM, F-29280 Plouzane, France

* Corresponding author: francois.le.loch@ird.fr

SPHYRAENA GUACHANCHO
BREEDING PERIOD
SEXUAL MATURITY
CÔTE D'IVOIRE

ABSTRACT. – To provide information for improving barracuda stock management on the Ivorian coast, the reproductive biology (length-weight relationship, sexual development and size at first maturity) of *Sphyraena guachancho* was studied in relation to the marine seasons and fish size classes. Samples were obtained between July 2010 and June 2011 from commercial fisheries in Abidjan fishing port. A total of 662 specimens (328 females, 334 males) with sizes ranging from 19 to 63 cm FL were analyzed. The sex ratio of *Sphyraena guachancho* was found to be slightly in favour of males (1: 0.98). The length-weight relationship is isometric for both sexes. The gonadosomatic index (GSI), hepatosomatic index (HSI), condition factor (K) and percentage of mature individuals for both sexes reveal that the breeding period corresponds to the Low Cold Season, mainly during January. The size at first maturity of the *Sphyraena guachancho* population is 28.8 cm. It was not significantly different between males (27.8 cm) and females (30.3 cm). Sexual maturity was found to be earlier than measured in previous studies at different locations.

INTRODUCTION

Global warming and overfishing have significant impacts on all aquatic biological systems, exposing species to local extinction risks for variable periods and causing related alterations of species assemblages (Cheung *et al.* 2009, Albouy *et al.* 2013) and trophic interactions (Albouy *et al.* 2014). The apex predators at the top of the food web may integrate or intensify these effects on ecosystems (Veit *et al.* 1997, Croxall *et al.* 2002, Cury, 2005). Under these changing conditions, fish predators may develop breeding strategies to ensure species survival (Potts & Wootton 1984; Murua & Saborido 2003). It has therefore become crucial to understand the reproductive biology of threatened fishes. Fish reproductive strategy is expressed by the length and duration of breeding period, spawning frequency and size at first maturity (Potts & Wootton 1984, Wootton 1998). These features are also fundamental for fish population management (Jennings *et al.* 2001).

The Sphyraenidae are top predators. On the West African coast, barracudas are among the fishes whose stock and catch average size are declining (Chavance *et al.* 2002, Gascuel 2002, Diallo *et al.* 2004, Gascuel *et al.* 2004). They also appear on the UNEP list of endangered species (Robertson *et al.* 2010). Faced with this situation, some countries such as Guinea have regulated their fish-

ing techniques and started to monitor fish breeding seasons (Baran *et al.* 2000).

Sphyraena guachancho is the main barracuda caught in most countries of the Gulf of Guinea (UNIDO-GEF-IGCC 2012). In Côte d'Ivoire, studies conducted by Daget & Iltis in 1965, Fager & Longhurst in 1968, and the more recent campaign of the N/R "Fridtjof Dr. Nansen" in 2000 (Azibile *et al.* 2012) also confirmed its presence in most landings of barracuda in Côte d'Ivoire. There is a general decreasing trend in *S. guachancho* landings for trawlers and seiners on the Ivorian coast (DAP, 2011).

To date, no attention has been paid to the reproductive strategy of this species. The study by Kromer *et al.* (1994) on the bioecology of barracuda in Guinea, focused only on *Sphyraena afra*. Matsuura & Suzuki (1997) and D'Alessandro *et al.* (2011) studied the ecological aspects of the larvae of *S. afra* in the southwest Atlantic. Information is lacking on the life strategy of *S. guachancho* both in Côte d'Ivoire and worldwide. As a consequence, no real management measures can yet be planned for this species. As reproduction is the starting point of recruitment that determines the number of individuals in a population, it is important to accurately determine the sexual cycle and size at first sexual maturity for this species.

This study presents reproductive indices that can be used to assess the reproductive behaviour of *Sphyraena guachancho* and contribute to improve stock management

in Côte d'Ivoire. Knowledge of the reproductive traits (fecundity, reproduction periods) would help to establish fishing management measures.

MATERIALS AND METHODS

Sampling: Barracudas were caught in the Ivorian Exclusive Economic Zone (ZEE) (Fig. 1), an area of 176,254 km², with 566 km of coastline in the central Atlantic Ocean. Seasonal hydroclimatic conditions of this area directly influence the availability of fishery resources due to a mean salinity of 35 and a sea surface temperature (SST) ranging from 23 to 30 °C (Arfi *et al.* 1993). According to Morlière (1970), SST in Ivorian waters is characterized by four separate climatic periods: a Great Cold Season (GCS), extending from July to September; an episode of Cold Season (Low Cold Season: LCS) usually observed every year from December to February (SST between 23 and 25 °C); the periods from March to June and October to November are referred to as the Great and Low Dry Seasons (GDS and LDS), respectively, with SST ranging between 28 and 30 °C. Individual barracudas were collected every month from July 2010 to June 2011 from commercial catches of trawlers in the Abidjan fishing port. The mesh was 140 mm at the entrance of trawls, decreasing gradually to reach 120 mm at the bottom. On board, fishes were immediately stored in ice blocks after fishing. The sampling was optimized to obtain the widest size ranges possible. Each individual was measured (Fork length FL, cm) to the nearest 0.1 cm using an ichthyometer. Body weight of the specimens was recorded on an electronic balance with 0.1 g precision. Sex was determined by abdominal incision and identification of sexual stages was made with the Sphyraenidae sexual maturity scale of De Sylva (1963) modified by Allam *et al.*

(2004), and then grouped according to the standardized terminology of Brown-Peterson *et al.* (2011). The rates of immature, developing, spawning capable, regressing, regenerating individuals were also recorded. Gonads and livers were weighed on an electronic balance with 0.0001 g precision.

Reproduction Index: Reproduction was characterized using the length-weight relationship, gonadosomatic index (GSI), hepatosomatic index (HSI), condition factor (K), proportion of mature individuals and size at first sexual maturity and sex-ratio.

Length-weight relationship was defined by the relationship:

$$W = aFL^b \quad (1)$$

By logarithmic transformation, a linear relationship is obtained:

$$\log W = \log a + b \log FL \quad (2)$$

where W = gutted weight of the individual, FL = fork length Index, a is a constant representing the y-intercept, b (slope of the regression line) characterizes the environment of species. It expresses the relative shape of the fish body. (Bert & Ecoutin, 1932, N'Goran 1995, Ouattara *et al.* 2008.). The Student t statistical test was used to characterize the allometry or isometry (Abdallah 2003) of the length-weight relationship.

The gonadosomatic index (GSI) is calculated as follows (Analbery 2004):

$$GSI = (PG / W) \times 100 \quad (3)$$

where Pg is the weight of the gonad.

Hepato-somatic index (HSI) is calculated as follows (Bougis 1952):

$$HSI = (Ph / W) \times 100 \quad (4)$$

where Ph is the liver weight in g.

Condition factor (K) is calculated as follow (Lalèye *et al.* 1995):

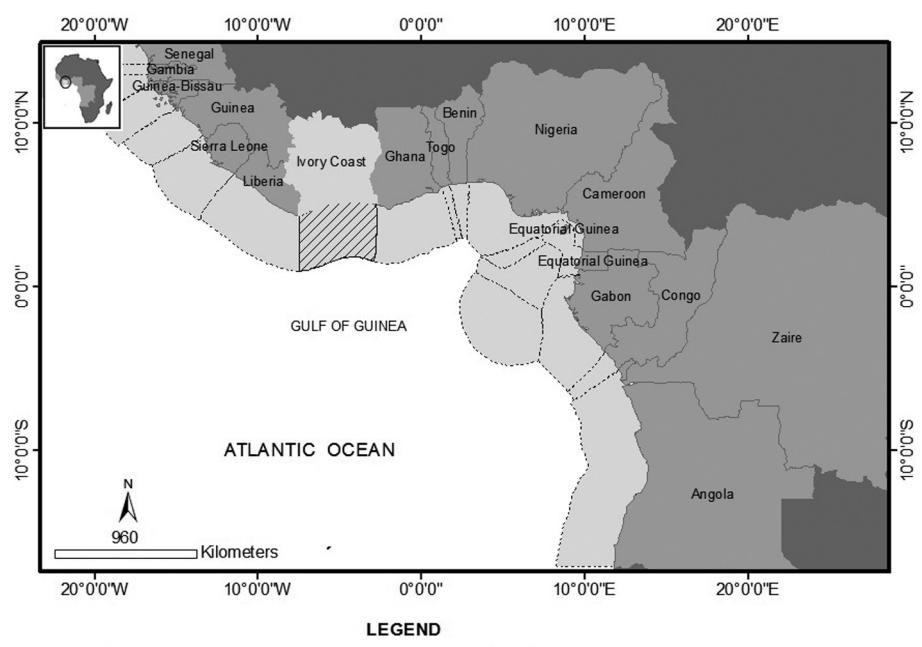


Fig. 1. – Location of the Exclusive Economic Zone (EEZ) of Côte d'Ivoire.

$$K = (W / FL_b) \times 1000 \quad (5)$$

The means of the reproductive parameters (gonadosomatic index, hepatosomatic index, condition factor and the proportion of mature individuals) and the length-weight relationship were compared between sexes and months by ANOVA using Statistica software.

Size at first sexual maturity (L_{50}) was defined by the Levenberg-Marquardt method (Marquardt 1963) using Statistica software. Percentages of sexual maturity stages were obtained for size classes of 1 cm difference and were adjusted with the following nonlinear regression function:

$$V_y = 1 / (1 + \exp(-a \times (V_x - L_{50}))) \quad (6)$$

where V_y = proportion of mature individuals in the size class and V_x = centre class corresponding to the proportion of mature individuals.

The sex ratio (SR) is calculated as follows (Albarete 1982):

$$SR = (Males / (Males + Females)) \times 100 \quad (7)$$

where Males and Females represent the number of males and females, respectively. The significance of monthly proportions of males and females was tested using the chi-square test.

RESULTS

Of the 662 sampled individuals, 328 (49.55 %) were females and 334 (50.45 %) males. Barracuda sizes and weights ranged from 19 to 61 cm FL (Fig. 2) and from 42 to 900 g, respectively (Table I).

Length-weight relationship

No sexual dimorphism was observed between males and females, although they were significantly different in size and weight (Table I). Also, variance analysis (Fisher's test) of the length-weight relationship between sexes, showed no significant difference ($F = 1.61$; $P = 0.21$). In the equation of the length-weight relationship of populations, $y = 0.0277x^{2.5761}$, coefficient b values were not significantly different from 3. Growth was isometric.

Monthly evolution of the gonadosomatic ratio by sex

The average female GSI (2.31 ± 1.45) was significantly higher than male GSI (1.27 ± 0.64) (Table II). The highest GSI values were observed in both sexes in January (female GSI = 4.35 ± 0.41 ; male GSI = 2.45 ± 0.60) and the lowest values in July (female GSI = 0.29 ± 0.20 ; male GSI = 0.21 ± 0.10) (Fig. 3A). GSI for both sexes was sig-

Table I. – Analysis of variance (Fisher test $P < 0.05$) on the length and weight between the two sexes. FL = fork length (cm); PV = empty weight (g). * = $p < 0.05$. Values are expressed as mean \pm standard deviation.

Parameters	Male	Female	F	P
Average length (FL)	35.79 ± 6.71	40.65 ± 9.03	10.058	0.001*
Average weight (PV)	303.80 ± 144.46	411.65 ± 211.83	9.90	0.002*

Table II. – Analysis of variance of reproduction parameters per sex. * = $P < 0.05$. Index averages by sex. GSI = gonadosomatic index; HSI = hepatosomatic index; K = condition factor; TM = proportion of mature individuals.

	Statistics			
	Females	Males	F	P
GSI	2.31 ± 1.45	1.27 ± 0.64	17.13	< 0.0001*
HSI	1.04 ± 0.37	0.73 ± 0.27	22.29	< 0.0001*
K	5 ± 1	6 ± 1	19.17	< 0.0001*
TM	11.08 ± 3.53	10.66 ± 2.82	0.016	< 0.0001*

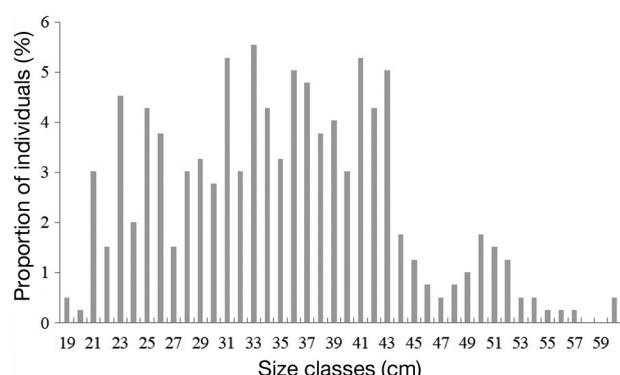


Fig. 2. – Proportion of individuals per 1 cm size class (N = 662).

nificantly different between LCS and the other seasons of the year (female F = 6.348, P = 0.00043; male F = 6.253, P = 0.00049) (Table IIIa, b).

Monthly evolution of the hepatosomatic ratio by sex

Females had a significantly higher average HSI (1.04 ± 0.37) than males (0.73 ± 0.27) (Table II). The highest values were observed in January for both sexes (1.49 ± 0.53 for females and 1.09 ± 0.23 for males; Fig. 3B). The lowest values were observed in April for males (0.37 ± 0.27) and in July for females (0.47 ± 0.05). The mean HSI for female per season was not significantly different with the HSI of the Low Cold Season and the other seasons. The HSI mean for male was significantly different in GCS and LDS.

Monthly evolution of the condition factor K by sex

Fig. 3C shows that the average condition coefficient for males (6) was far higher than for females (5). Monthly monitoring shows that the lowest value was in January for male and female (0.005 and 0.004, respectively). The highest values were observed in October for males (7) and November for females (6). When comparing the mean for female between seasons, a significant difference was found between the Low Cold Season and the rest of the year (F = 15.229; P = 0.00000). The

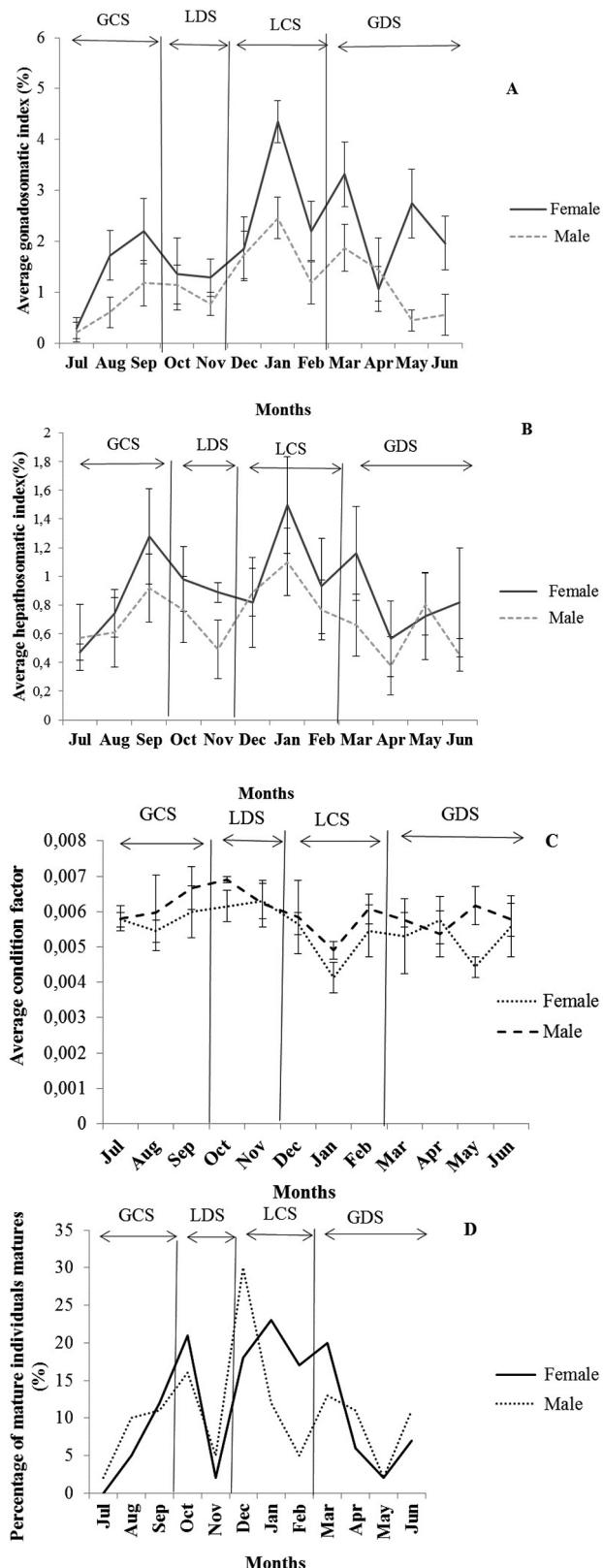


Fig. 3. – Evolution of reproductive indices of males and females over the year ($N = 662$, females = 328, males = 334). A: Gonadosomatic index (GSI), mean \pm standard deviation; B: Hepatosomatic index (HSI), mean \pm standard deviation; C: Condition factor (K), mean \pm standard deviation; D: Maturity rate. Great Cold Season (GCS), Low Cold Season (LCS), Great Dry Seasons (GDS) and Low Dry Seasons and (LDS).

same result was observed for males ($F = 4.717$; $P = 0.00349$) with the exception of GDS (Table IIIb).

Monthly and seasonal evolution of percentage of mature individuals by sex

The maturity rate was highest for females, with a significant difference in the proportion of mature individuals observed between the sexes (Table II). The percentages of mature individuals every month was above 50 %, except in July (36 %) of the GCS (Fig. 3D). The highest values were recorded in the Low Cold Season (December to February) when there were 100 % mature individuals. The rates of mature individuals per season for both sexes did not show a significant difference between the proportion of mature individuals in the Great Cold Season and the proportions in other seasons (Females, $F = 1.8358$, $P = 0.218$; Males, $F = 0.570$, $P = 0.65$).

Size of first maturity by sex

Females were shown to reach maturity later than males (Fig. 4), but this difference was not significant ($F = 0.002$; $P > 0.05$). However, the smallest mature individual male measured 23.5 cm and female was 25.5 cm.

Evolution of the sex ratio

The overall sex ratio was slightly in favour of males (1: 0.98; $P = 0.81$), but this was not significant. The sex ratio did however vary seasonally. The proportion of males was higher in GDS and GCS, specifically in June (1: 0.6; $P = 0.00086$) and August (1: 0.33; $P = 0.02$). In contrast, female dominance was particularly evident in February (1: 3.40; $P = 0.01$) in LCS. The proportion of males decreased gradually as size increased ($X^2 = 77.34$; $P < 0.00000$). For individuals smaller than size at first

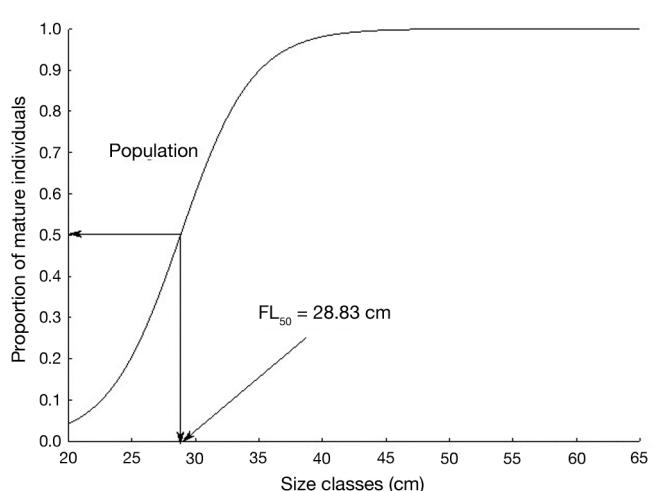


Fig. 4. – Size at first maturity = FL_{50} . ($N = 662$).

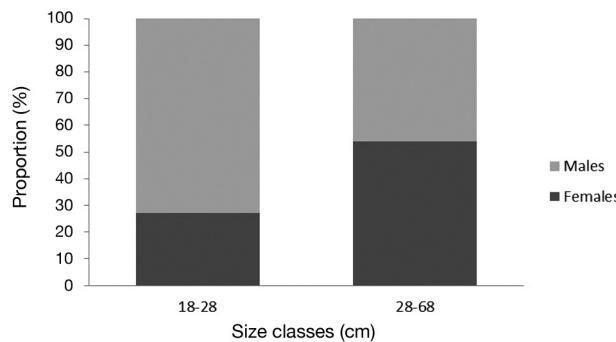


Fig. 5. – Proportion of males and females on both sides of the first maturity length (N = 662, females = 328, males = 334).

maturity, males were dominant. Above this size, females were more frequent (Fig. 5).

DISCUSSION

Studies on the reproduction of the genus *Sphyraena* are very scattered and have been performed on species from different geographic regions. Nevertheless, they provide important basic information on the biology of these species (O'Toole, 2008).

For the western Atlantic, De Sylva (1963) and Kadison et al. (2010) investigated the life cycle of *S. barracuda* in Florida; Bay & Cadenat (1964) commented on the reproduction of West African barracudas *S. sphyraena*, *S. viridensis*, *S. barracuda*, *S. dubia* and *S. piscatorum*. The present study is the first that monitored breeding indices and assessed sex ratio, sexual cycle and size at first maturity of *Sphyraena guachancho* on the Ivorian coastline.

The present research on reproductive indices in *Sphyraena guachancho* in the equatorial Atlantic Ocean revealed no sexual dimorphism. De Sylva (1963) mentioned that there is no evident external sexual dimorphism among sphyraenids although males reach sexual maturity at a smaller size than females. Bourehail et al. (2010) noted that an exception was made for *S. viridensis* in eastern Algeria, where sexual dimorphism appears above the age of 4 years.

Size and weight by sex of *S. guachancho* are not equivalent. Zavala-Leal et al. (2018) have made the same remarks for *S. ensis*. These authors mentioned that Nikolsky (1963) suggested that females reach greater lengths as a reproductive strategy, for this allows them to produce more eggs. However, significant difference in the length-weight relationship between sexes is consistent with de Sylva (1963) and Kadison et al. (2010). The isometric growth of *S. guachancho* has been revealed by Bedia et al. (2011) but they noted that different types of growth have been detected according to the sampling season (isometric growth in the rainy season and allometric in windy and dry seasons). However, isometric growth

Table IIIa. – Analysis of variance on female reproduction indices across seasons. * = p < 0.05. Values are expressed as mean ± standard deviation. Same letter indicates there is no significant difference between the values. N = 662. GSI = gonadosomatic index; HSI = hepatosomatic index; K = condition factor; TM = the proportion of mature individuals. The different letter in the column indicated significant difference (P < 0.05)

Female	Season	Mean	F	P
GSI	LCS	2.9465 _a ± 0.231	6.348	0.00043*
	GDS	2.9910 _b ± 0.268		
	GCS	1.8027 _{b,c} ± 0.321		
	LDS	1.3577 _c ± 0.315		
HSI	LCS	0.00563 _a ± 0.0736	1.2454	0.02954
	GDS	0.00569 _a ± 0.085		
	GCS	0.00618 _a ± 0.103		
	LDS	0.00672 _a ± 0.0997		
K	LCS	0.005 _a ± 0.00047	15.229	0.00000*
	GDS	0.00542 _b ± 0.005175		
	GCS	0.00587 _c ± 0.00617		
	LDS	0.0617 _c ± 0.006467		
TM	LCS	19.333 _a ± 9.27	1.83586	0.218
	GDS	8.75 _a ± 3.77		
	GCS	5.6667 _a ± 4.361		
	LDS	11.500 _a ± 5.34		

Table IIIb. – Analysis of variance on male reproduction indices across seasons. * = p < 0.05. Values are expressed as mean ± standard deviation. Same letter indicates there is no significant difference between the values. N = 662. GSI = gonadosomatic index; HSI = hepatosomatic index; K = condition factor; TM = the proportion of mature individuals.

Male	Season	Mean	F	P
GSI	LCS	1.8613 _a ± 0.1837	6.2530	0.00049*
	GDS	1.335 _{ac} ± 1.333		
	GCS	0.72845 _b ± 0.728		
	LDS	1.0481 _{bc} ± 1.048		
HSI	LCS	0.92511 _a ± 0.0892	2.8681	0.03862*
	GDS	0.55895 _a ± 0.089254		
	GCS	0.72351 _{ac} ± 0.093834		
	LDS	0.68741 _{bc} ± 0.109313		
K	LCS	0.00563 _a ± 0.000202	4.717	0.00349*
	GDS	0.00569 _a ± 0.000200		
	GCS	0.00618 _{ab} ± 0.000216		
	LDS	0.00672 _b ± 0.000257		
TM	LCS	7.66 _a ± 4.630	0.57047	0.65001
	GDS	10.55 _a ± 5.671		
	GCS	15.667 _a ± 4.63044		
	LDS	9.25 _a ± 4.010078		

was also inferred in *S. obtusata* (Jaiswar et al. 2004), for *S. putnamae* (Mohammadizadeh et al. 2010) and *S. idiastes* (González-Acosta et al. 2015)

Monthly sex ratio monitoring revealed that proportions of males and females were not constant over the year.

Hosseni *et al.* (2009) found the same result for *S. jello* in the Persian Gulf, as did Sohair *et al.* (2004) in their study of the barracudas in the Mediterranean Sea. The sex ratio change might be due to the migration of prelaying females. Females migrate to build up energetic reserves that they will later use during reproduction (De Sylva 1963).

The seasonal sex ratio monitoring reveals an abundance of females, especially during the Low Cold Season (December to February). Males are dominant during other seasons, mainly in the Great Dry Season and Great Cold Season. This seasonality in the relative abundance of the sexes also occurs in other species of the same genus. It is particularly intense in *S. viridensis* (Bareiro *et al.* 2002) in the Azores, and less pronounced in *S. barracuda* (Paterson 1998) on the São Tome and Príncipe Island and near oil platforms. According to the same authors, seasonal aggregation of females would occur for breeding purposes.

The study of sex ratio by size class reveals a predominance of males among individuals which had not reach the size at first maturity (< 28 cm), and females among mature individuals (> 28 cm). These findings confirm those of Sohair *et al.* (2004). Indeed, in Sphyraenidae, males are generally more abundant in small size classes (Allam *et al.* 2004). These dominance changes in favour of one sex or the other could be due, among other things, to early maturity and slower growth in males (Hashem 1981, Kartas & Quignard 1984). In 1964, Cadenat noted this precocity in *S. guachancho* (between 49 and 55 cm in males and in females between 55 and 65 cm). This observation was not, however, confirmed in the present study, as the size measured at sexual maturity was not significantly different between the sexes. For several species of fish in general and particularly for Sphyraenidae, males reach sexual maturity at a smaller size than females and this could be associated with the shorter lifespan of males compared with females (Faltas 1993, Rhageb 2003). *Sphyraena guachancho* sexual maturity was however earlier here for both sexes than found by Cadenat (1964). Kromer *et al.* (1994) observed the smallest mature individual at 35 cm, which was smaller than Cadenat's (1964) measurements but larger than our own. Our results, which differ from those of other authors, reflect a precocious maturity of the species off the Ivorian coast. This reduction in the population renewal time through early sexual maturity could be a strategy adopted by the species to increase the chances of surviving and reproducing as well as stock renewal capacities (Law 2000, Gerritsen *et al.* 2003, Hutchings & Baum 2005). In fact, the response of a fish population to fishing pressure is a more rapid renewal of its stock (Hawkins & Roberts 2002). Such fishing activity can have multiple inputs, including stock rejuvenation and continuous reproduction throughout the year (Lae 1997).

Analysis of the evolution of the rate of mature females and their HSI and GSI indices suggests that the favourable spawning period occurs during the Low Cold Season. Indeed, the evolution of these indicators over time only shows one statistically significant peak in Low Cold Season, mainly in January. Breeding therefore occurs during the LCS. According to De Sylva (1963) and Kadison *et al.* (2010), this activity only happens once in the year and is related to water temperature (close to 23 °C for *S. barracuda* in Florida). In addition, spawning observed during this period causes a decrease in condition (condition factor K) in December and February (Low Cold Season) for females. This result is explained by the fact that trophic conditions are not optimal in the Low Cold Season and fattening of *S. guachancho* slows or ceases. It therefore uses the accumulated reserves to ensure continuous development of gametes, hence explaining the decline in condition. For the males, these indices also suggest a single spawning period, which coincides with that of the females during the Low Cold Season. In short, the overall monitoring of the reproductive indices for the establishment of the sexual cycle of *S. guachancho* in Côte d'Ivoire shows that the spawning period would occur most likely during Low Cold Season and corresponds to weight loss in both sexes. Zavala-Leal *et al.* (2018) did not observe an inverse relationship between K and GSI, but noted a slight decrease in the condition factor during *S. ensis* spawning period.

However, the spawning period observed here for *S. guachancho* is not the same as that observed by Cadenat (1964) in Senegal (Eastern Central Atlantic), which was between July and September. In the Guinean region, IUCN (2000) reported that spawning of *S. afra*, the most abundant and commercially most important barracuda in the area, occurs from July to August. Observations made by D'Alessandro *et al.* (2007) in Florida extended this period of reproduction from July to October, although these authors mentioned that their quantity of samples for this species was so small that they could not formally represent significant spatial and temporal distribution. These differences in results confirm the hypothesis of O'Toole (2008) whereby reproductive activity as well as the growth of Sphyraenidae vary with geographical area.

The curve shapes of GSI and HSI have the same trends for both sexes at spawning periods. Villegas Hernandez *et al.* (2014) observed the same pattern for *S. sphyraena*. The curve tendency of K is opposed for the two sexes in GDS. Indeed, *S. guachancho* females lose weight in GDS. These phenomena are in relation with the reproductive strategy based on different components of breeding systems in marine fishes. Fishes can be total or batch spawners (Wotton 1990). Macroscopic analyses of gonad revealed five level evolutions. However, there is an uncertainty on the dynamic base of the organisation of the ovary which was described by Marza (1938) and Wallace & Selman 1981 in Murua & Saborido-Rey (2003). In this

work, the reproductive index of *S. guachancho* confirmed a single reproduction.

Mean GSI and HSI were higher in females than males. However, these observations do not imply that they have more intensive reproductive activity than males. These differences could be due to weight variations observed between males and females. They would mainly be under the influence of gonad condition. In fact, there is a very close correlation between the ovaries and liver size in teleosts (Fauconneau *et al.* 1990, N'Da 1992, Weil *et al.* 2012). These variations, estimated by the hepato-somatic ratio, could be due to movements of fats in the liver. These fat reordering (accumulation and release of lipids) is related to diet and sexual activity (Cartier *et al.* 2004).

The determination of reproductive traits is the starting point of recruitment, which determines the number of individuals in a population. Thus, the knowledge of the reproductive traits (reproduction periods, fecundity) would help in the stock management. The identification of the period of eggs maturation and spawning is required to appropriately estimate the fecundity and reproduction potential of a species (Murua & Saborido-Rey 2003). In order to assess the levels of exploited stocks, additional information on the growth and intensity of fishing activity would also be required.

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