International Journal of Zoology and Applied Biosciences **ISSN: 2455-9571**
Volume 8, Issue 6, pp: 26-32, 2023
https://doi.org/10.55126/ijzab.2023.v08.i06.004
http://www.ijzab.com

Research Article

REPRODUCTIVE BIOLOGY OF THE FLYING GURNARD *DACTYLOPTERUS VOLITANS* (Linnaeus, 1758) FROM THE COASTAL WATERS OF COTE D'IVOIRE

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Article History: Received 16st August 2023; Accepted 23rd October 2023; Published 18th November 2023

ABSTRACT

The flying gurnard *Dactylopterus volitans* is one of the most important by–catch fish species in the inshore trawl fisheries of Côte d'Ivoire. Its reproductive characteristics were studied in order to provide fisheries managers with the essential data for science–based management. A total of 1337 specimens (including 351 males and 986 females) with size 60–390 mm in standard length (SL) were caught by industrial trawlers in waters of Côte d'Ivoire between January 2019 and December 2020. The sex ratio was defined as the proportion of females to males following month and marine seasons. The reproductive activity was assessed using the gonadosomatic index and the percentages of maturity stages. The overall sex ratio of 1 female for 0.36 male was in favour of females (χ^2 = 301.59 p < 0.05). At 50% sexual maturity, males matured at of 192.8 mm, SL while females matured at 158.6 mm. The flying gurnard spawned twice during a relatively long reproductively active period, from May to August and from November to February. The total fecundity ranged from 4164 to 112232 oocytes/ovary and showed a significant correlation with fish length and body weight. This information will contribute to a scientific basis for future management.

Keywords: Industrial trawlers, Sex ratio, Sexual maturity, Spawning.

INTRDUCTION

Exploited marine species provide a means of livelihood and financial income for humans (FAO, 2018). However, they face threats from overexploitation and habitat degradation (Caddy, 1993). In the Gulf of Guinea, most of demersal species are overexploited (COMHAFAT, 2014). In Côte d'Ivoire, even by-catch species that were considered to be of no commercial value are increasingly being landed and traded. The flying gurnard, *Dactylopterus volitans* (Linnaeus, 1758) is a small demersal species commonly distributed in eastern Atlantic coasts, from the English Channel to Angola, including the Mediterranean, Madeira, and the Azores, and the western Atlantic, from Canada to Argentina (Froese and Pauly, 2013). It found on sand, mud or over rocks in sandy areas at depths of 1–100 m, exploring the bottom with the free part of the pectoral fins (Roux, 1986). This species is one of the most important by–catch fish species in the inshore trawl fisheries and is used as bait for several tuna fisheries. According to Abbey *et al.* (2016) the flying gurnard is of high nutritional significance in either human food supplements or formulations, as it has a high protein content, good general amino profile, and abundance of polyunsaturated fatty acids. Although it is regarded as of no statistical importance due to its low commercial value, this species has been characterized by high appreciated flesh and good market perspectives in Côte d'Ivoire. Given its high abundance in the landing sites, studies focused on its reproductive biology are necessary to design and implement strategies to support fishery or conservation management. In fact, the knowledge of the period and spawning grounds is fundamental for the establishment of time-area closures to

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protect and ensure spawning and consequent recruitment of species (Goodyear, 1999; Armsworth *et al*., 2010). Or the implementation of these fisheries management plans is difficult due to the lack of adequate biological data on this species. To our knowledge, there is no study on the reproductive biology of the flying gurnard in the eastern central Atlantic in general and in the Gulf of Guinea in particular. The present study aims to define the reproductive characteristics of the flying gurnard, *Dactylopterus volitans* in the coastal waters of Côte d'Ivoire in order to understand the annual cycle of its reproductive development.

MATERIALS AND METHODS

Sampling and laboratory processing

Sample of flying gurnard come from the industrial bottom trawlers catches, which operate along the coast of Côte d'Ivoire **(**Figure 1**)**. The seasonal hydroclimatic of this area conditions directly influence the availability of fishery resources due to a salinity of more than 35 and a surface sea temperature ranging from 23 to 30°C (Arfi *et al.*, 1991). According to Morlière and Rebert (1972), it is characterised by four main seasons with two warm seasons (March–June and November–December) and two cold seasons (July–October and January–February). About of 30 to 87 specimens were sampled monthly from January 2019 to December 2020 at the fishing harbour of Abidjan where trawlers, seiners, and purse seiners stored their catches immediately in ice after fishing. Fish samples were brought to the laboratory and the standard lengths (SL) and weights were measured to the nearest 1.0 mm and 0.01 g, respectively. Each individual was then dissected, sexed, and the gonads were removed and weighed to the nearest 0.001 g, as well as the eviscerated weight to the nearest 0.01 g. A large collection of flying gurnards in the study period made it possible to develop a maturity schedule for each sex. Gonads were staged macroscopically, according to a protocol adapted from Fontana (1969) and Pankhurst *et al*. (1987) as follows: Stage I (immature): thin, white or slightly translucent testes. Small and thin transparent or light pink ovaries occupying a small part of the body cavity – invisible oocytes; Stage II (early maturing): whitish testicles, larger and more consistent than stage I. Ovaries slightly larger firm and pale pink to light orange in colour – ovary small and round, pale pink oocytes are sometimes visible through the ovarian membrane.; Stage III (developing): firm whitish gonad; no liquid flows if an incision is made. Larger and less firm ovaries usually light orange then dark–oocytes visible through the ovarian membrane make the surface of the ovary granular; Stage IV (pre–spawning): softer and white testes – a whitish fluid flows out as soon as an incision is made. More enlarged ovaries occupying the entire abdominal cavity with larger oocytes that cannot be expelled by manual pressure. Stage V (spawning): testes large and soft – the sperm flows when pressure is exerted on the abdomen. Very large ovaries occupying the whole abdominal cavity – very thin ovarian membrane – the hyaline and large oocytes are perfectly visible and are expelled at the slightest pressure on the abdomenand some ripped eggs are free in the oviduct; Stage VI (spent): testes are flaccid and have a very fine and/or strong vascularisation especially in the posterior part. Ovaries bloody, flaccid, flattened in shape and very vascularised – its colour varies from salmon pink to red – through the ovarian membrane the oocytes are perfectly visible– numerous hyaline spaces present.

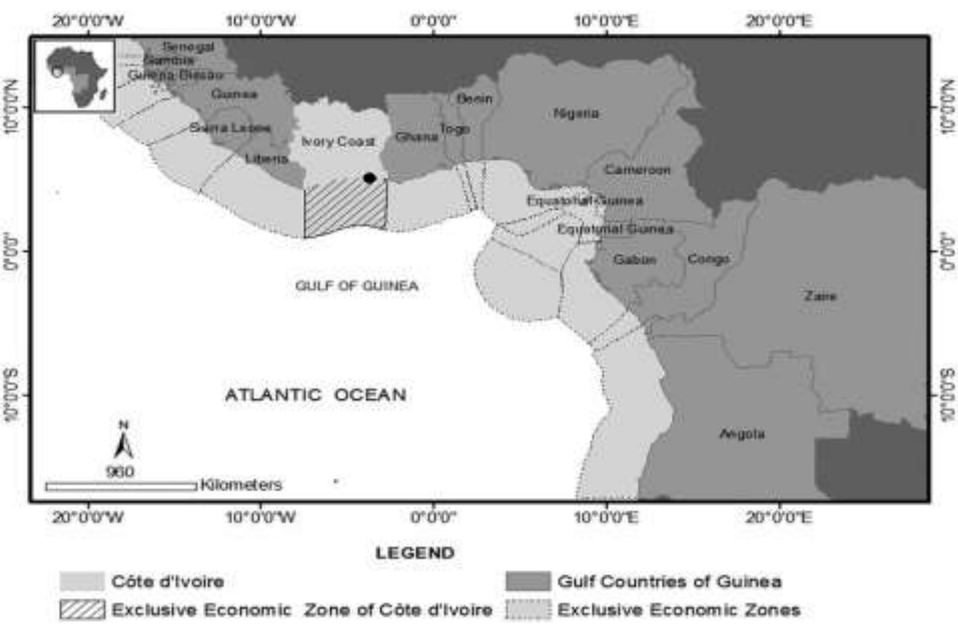

Figure 1. Study map showing landing (●) and sampling areas (▨) for the flying gurnard *Dactylopterus volitans.*

The sex ratio was determined using the proportion of the number of males to that of females. To eliminate possible error, data for establishing length at maturity were only collected during the period of maximum gonad activity. Fish with gonads in Stages I and II were regarded as being immature, and fish with gonads in the subsequent Stages III to VI were considered to be mature. Average size at first maturity (L_{50}) was defined as the standard length at which 50% of individuals in the population reached sexual maturity during the reproduction period considering gonads of stage greater than or equal to 3 as mature fish. Fish were grouped into 10 mm size classes and twenty to thirty individuals examined within each. The L_{50} was estimated using the logistic regression model by fitting the fraction of mature fish against the total length. This model was described by Echeverria (1987) as follows:

$$P = \frac{e^{(\alpha+\beta TL)}}{1+e^{-(\alpha+\beta TL)}}$$

where P = percentage of mature fish, SL = standard length, and α and β = coefficients.

The value of L_{50} was estimated from the negative ratio $\frac{-\alpha}{\beta}$ by substituting P = 0.5.

The gonadosomatic (GSI) index, which represents the gonad mass expressed as a percentage of the wet body mass, was estimated according to the method of Vazzoler (1963) using the following equation:

$$GSI = \frac{\text{Gonad mass (g)}}{\text{Eviscerated mass (g)}} \times 100$$

The batch fecundity is the number of oocytes likely to be released at the next spawning. In *D. volitans*, the oocyte distribution in the ovary is bimodal and ripe females (stage IV) are more likely to lay oocytes with the highest modal diameter. Therefore, only the stage IV gonads from females were used to estimate the fecundity. After weighing the ovaries, three sub-samples of 0.1 g each taken from the middle, front and back of each ovary were used to count the migratory nuclei and hydrated oocytes. Migratory nuclei and hydrated oocytes can readily be distinguished from other oocytes by their larger size and appearance. Each of the three subsamples yielded an estimate of batch fecundity for each female, calculated from the product of the number of migratory nuclei or hydrated oocytes per unit weight of the subsample and the total weight of the ovaries. The mean of these three estimates provided the spawning batch fecundity estimate for each fish. Regression analysis was conducted to quantify and explore the relationship between batch fecundity and total length.

Oocyte diameters were measured under a Wild M3C dissecting stereomicroscope fitted with a calibrated ocular micrometre. A small sample of about 0.5 g was taken from anterior, mid, and posterior part of each ovary. This sample was placed in a small glass tube containing 5% formalin. After 3 to 4 days and after repeated shaking of the tube, the ovarian stroma dissolved and the oocytes detached easily from each other, then the diameters of 60–90 oocytes were measured.

Statistical analyses

The Shapiro-Wilk normality test for homoscedasticity were applied to the data, to determine whether one of the assumptions of the parametric and nonparametric analyses for abiotic parameters, sex ratio and GSI were satisfied. The size distribution plot and Kolmogorov–Smirnov test (K-S) considering a significant level of 95% were applied to compare the size-frequency distribution between sexes. A χ^2 test was applied to test the significant differences between the sex ratio of females and males. The growth type was identified by Student's t-test. A one-factorial ANOVA was performed to analyse the monthly variations of mean GSI values for each separate sex. Tukey's HSD multiple contrasts test was used to determine significant differences at the 0.05 level.

RESULTS AND DISCUSSION

A total of 1337 specimens of which 351 males (26.25%) and 986 females (73.75%) with sizes of 60–360 mm SL for males and 90–390 mm for females were collected (Table 1). The corresponding weights were14.5-711g and 17-901 g. No statistically significant difference between the length distribution of males and females flying gurnard specimens collected during the entire survey period was detected (Kolmogorov-Smirnov test, $p > 0.05$), although catches were almost exclusively dominated by females. So, the data was a reasonably good fit with the normal distribution. The overall male to female ratio (0.36: 1) was significantly different from the theoretical sex ratio 1:1 in favour of female ($\chi^2 = 369.64$; $p<0.05$). Females dominated monthly throughout the year, except in February and September where males outnumbered females.

Table 1. Monthly variation in the sizes and sex ratio of *Dactylopterus volitans* caught from January 2019 to December 2020 in the coastal waters of Côte d'Ivoire.

	Males		Females		Sex ratio		
Month	$SL_{min–max}$	Number	$SL_{min–max}$	Number	M: F	χ^2	*p-value*
Jan	60–235	36	90–374	88	0.41: 1	21.81*	0.00000
Feb	60–360	69	90–390	45	1.53: 1	5.05*	0.02149
Mar	170–330	23	160–330	85	0.27: 1	35.59*	0.00000
Apr	160–271	20	116–305	101	0.19: 1	54.22*	0.00000

May	145–305	19	135–300	66	0.28: 1	25.99*	0.00000
Jun	170–348	4	135–389	67	0.06: 1	55.90*	0.00000
Jul	115–260	12	120–340	78	0.15: 1	48.40*	0.00000
Aug	165–285	27	140–362	91	0.29: 1	34.71*	0.00000
Sep	150–251	69	115–340	35	1.97: 1	11.12*	0.00042
Oct	124–240	39	140–360	73	0.53: 1	10.32*	0.00075
Nov	110–220	12	136–360	116	0.1: 1	84.50*	0.00000
Dec	120–220	21	117–335	141	0.14: 1	88.89*	0.00000
Total	60–360	351	90–390	986	0.36: 1	301.59*	0.00000

* = significant difference

Table 2. Seasonal variation in the size and sex ratio of *Dactylopterus volitans* captured from January 2019 to December 2020 in the coastal waters of Côte d'Ivoire.

	Males		Females		Sex ratio		
Seasons	SL $_{min–max}$	Number	SL $_{min–max}$	Number	M: F	χ^2	*p–value*
MCS	60–360	105	90–390	133	0.79:1	3.29	0.06760
GWS	145–348	66	116–385	319	0.2:1	166.26*	0.00000
GCS	115–285	147	115–362	277	0.53:1	39.86*	0.00000
MWS	110–220	33	117–360	257	0.13:1	173.02*	0.00000
Total	60–360	351	90–390	986	0.36:1	301.59*	0.00000

* = significant difference, MCS = minor cold season, GWS = great warm season, GCS = great cold season, MWS = minor warm season

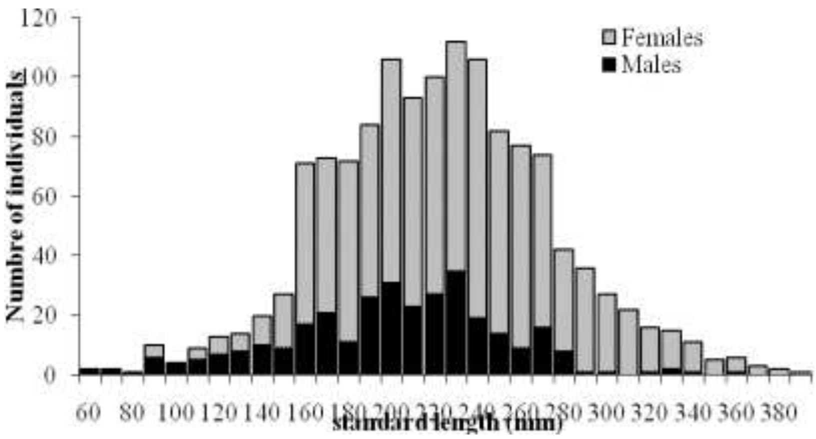

Figure 2. Length–frequency distribution for male and female of the flying gurnard *Dactylopterus volitans* caught in the coastal waters of Côte d'Ivoire from January 2019 to December 2020.

The sex ratio also varied greatly following marine seasons and size groups. Females were predominant in all seasons (Table 2) whereas following fish size, the sex ratio was biased to males in size of 60–130 mm SL and males in size above 150 mm (Figure 2). The size at first sexual maturity was 192.8 mm for males and 158.6 mm for females (Figure 3). Thus, females reach sexual maturity at smaller size than males.The smallest male with ripe gonads was 133 mm SL and weighed 90 g, while the smallest ripe female was 125 mm SL and weighed 44.5 g. Mean GSI (years pooled) of males and females showed the same trend (Figure 4).The GSI fluctuated monthly (Anova test, df = 11, F = 6.24, $p < 0.05$) with values increasing from March to June, followed by a decrease in July-September. A second increase in GSI occurred from October, reaching a peak in December and then declining from January to February. Females with high GSI were frequently observed in March–June (1.54 ± 0.48–1.80 ± 0.21) and December (2.06 ± 0.47) where as mean GSI of males was high in June (1.28 ± 0.22) and December (1.00 ± 0.35). Low values were recorded in

February (0.16 ± 0.11 and 0.71 ± 0.33) and September (0.18 ± 0.10 and 1.19 ± 0.48) for males and females respectively. Regarding the percentage of maturity stages, the spawning or spent gonads (stages V and VI) were found throughout the year. In addition, ovary and testis samples were all in spawning or spent stage in June–August and December–February (Figure 5). So, the peak spawning periods of this species were from May to August and from November to February. Most of spent females occurred in July–August and January–February, corresponding to the peak of spawning.

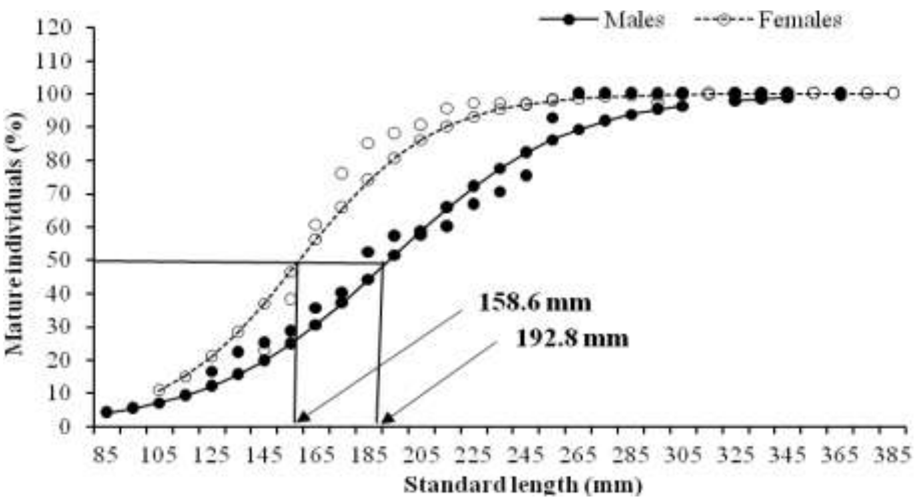

Figure 3. Length at first maturity estimation of the flying gurnard *Dactylopterus volitans* for females and males in the coastal wateurs of Côte d'Ivoire.

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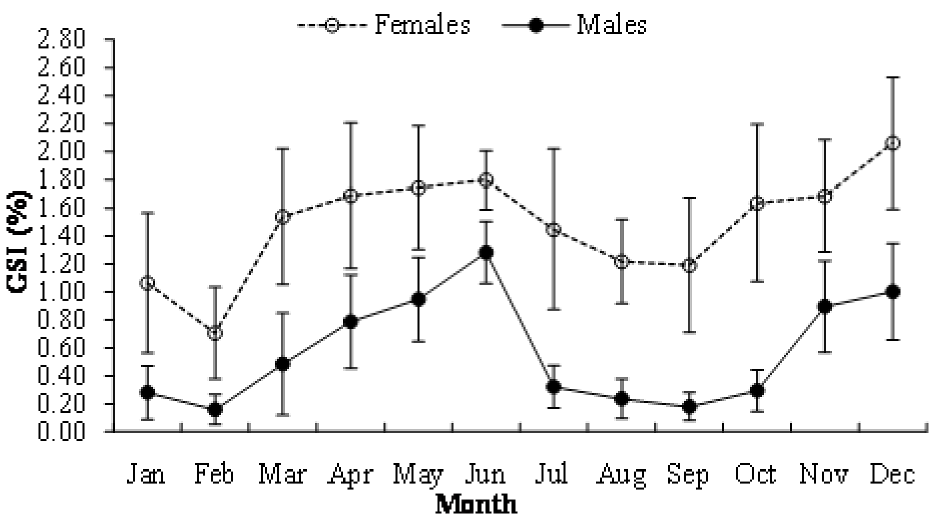
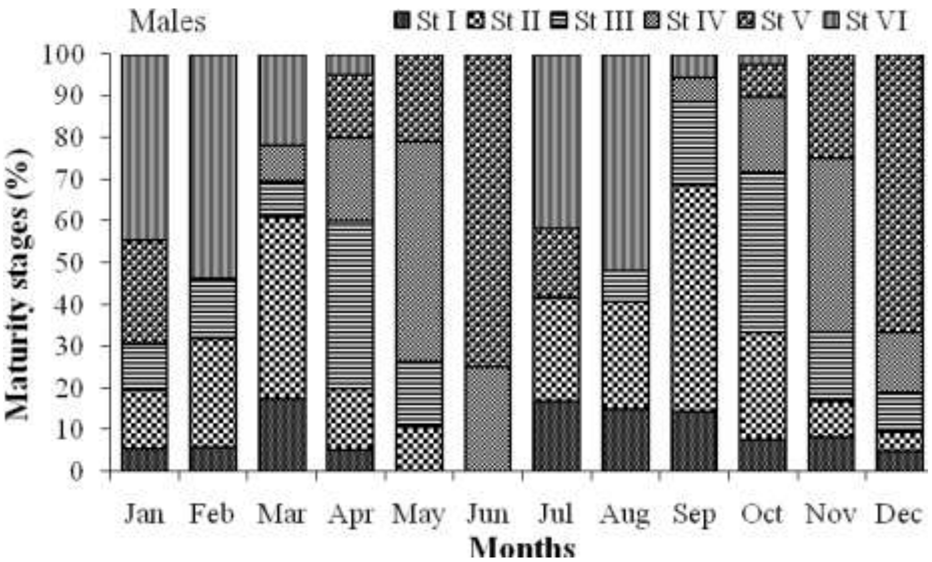


Figure 4. Monthly average gonadosomatic index (GSI) values (%) with standard error per month for females and males of the flying gurnard *Dactylopterus volitans* in the coastal waters of Côte d'Ivoire.



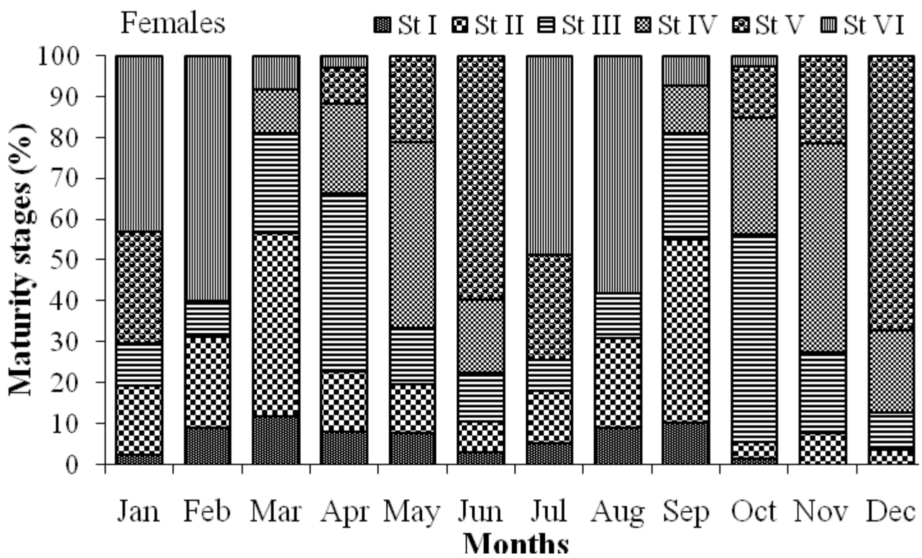


Figure 5. Percentage of maturity stages for the flying gurnard *Dactylopterus volitans* in the coastal waters of Côte d’Ivoire from January 2019 to December 2020. StI: immature; StII: early maturing; StIII: developing; StIV: pre-spawning; StV: spawning; StVI: spent.

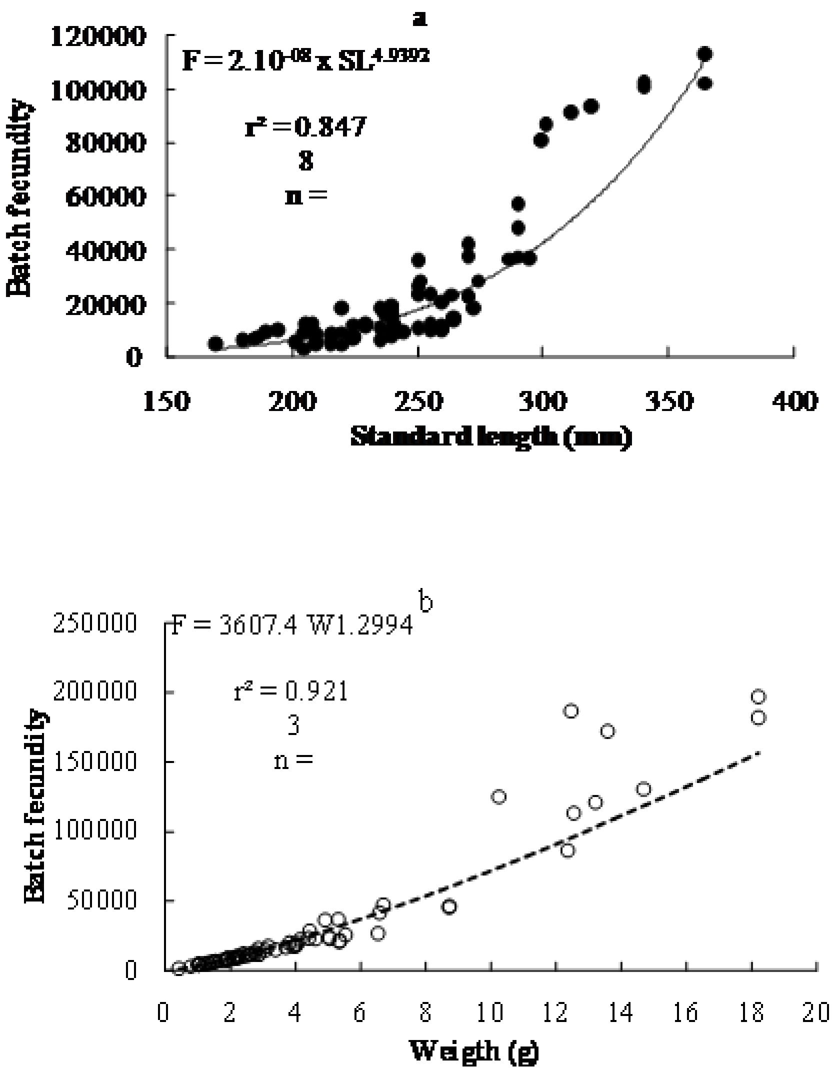
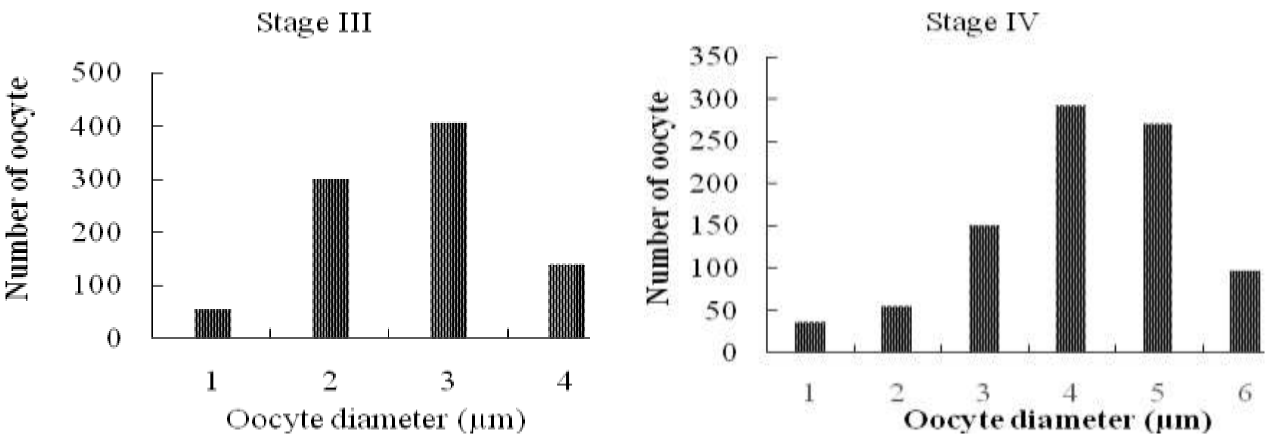


Figure 6. Relationships between batch fecundity–standard length (a) and batch fecundity–weight (b) of the flying gurnard *Dactylopterus volitans* in the coastal waters of Côte d'Ivoire.



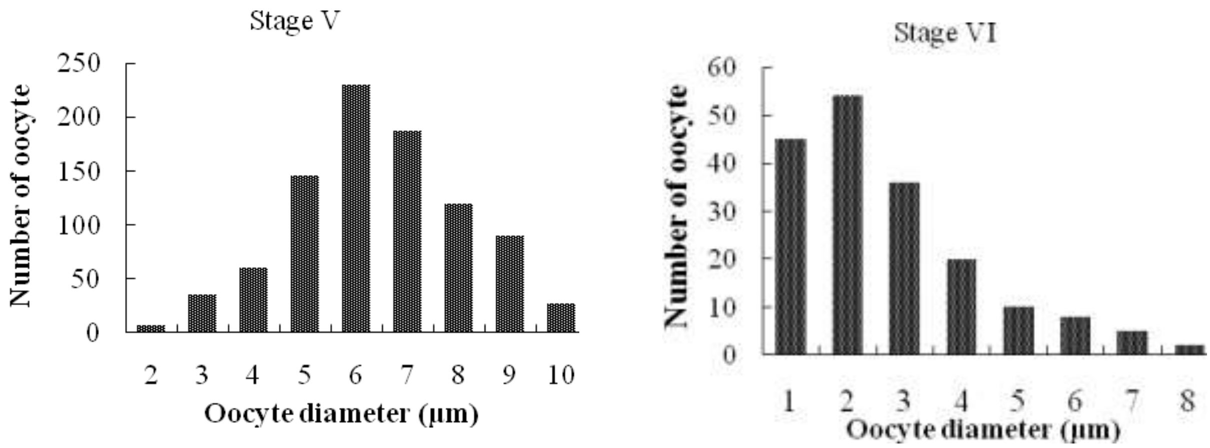


Figure 7. Oocyte diameter frequency distribution from stages III to VI of the flying gurnard (*Dactylopterus volitans*) in the coastal waters of Côte d'Ivoire from January 2019 to December 2020.

The fecundity was estimated for 73 females of sizes ranged from 170 to 365 mm, SL and weights of 93–710.5 g. The batch fecundity varied from 4164 to 112232 oocytes. The fecundity (Figure 6) was strongly related to both standard length (r^2 = 0.8478) and body weight (r^2 = 0.9213).All development stages of oocytes were present in each stage throughout the year. Oocytes diameter ranged from 1 to 4 µm in stage III, from 1 to 6 µm in stage IV, from 2 to 10 µm in stage V and from 1 to 8 µm in stage VI (Figure 7). The study exposes the reproductive feature (sex ratio, sexual maturity, spawning season and fecundity) of the flying gurnard in waters of Côte d'Ivoire. It is expected that that sex ratio varies from the expected 1:1 from species to species, or even in the same population at different times, being influenced by several factors such as adaptation of the population, reproductive behaviour, food availability and environmental conditions (Nikolsky, 1963; Vandeputte *et al*., 2012). However, our findings for this species showed that there was a statistically significant difference from this equality, as the sex ratio was found to be 1 female to 0.36 male in the studied samples. This dominance of one sex over another is a relatively common phenomenon in most teleost fish species according to Poulet (2004). Similar results of female–skewed sex ratios have been previously reported for the main gurnard species in water bodies including the Sea of Marmara in Turkey, the eastern Libyan coast, the south-eastern Adriatic Sea in Croatia and the Dernah coast in eastern Libya (Eryilmaz and Meriç, 2005; Dobroslavić *et al*.,2021). According to Penman and Piferrer (2008) sex determination is the genetic or environmental process by which sex is determined in a simple binary fate decision. On the other hand, number of females is more than the number of males according season and large fish sizes groups. We assume that the predominance of females results from the fact that they were more susceptible to exploitation because of their sedentary at the spawning grounds.

The size at first sexual maturity of fish species might be differed due to feeding rate, sex and gonadal development, behaviour, season, flow of water, populations density, water temperature and foods (Tarkan *et al*., 2006; Hossain *et al*., 2012). According to Mohammad (1982) and El-Mor (1993) in natural fish community males mature first before females, and become ready to participate in spawning activity. This phenomenon is attributed to the fact that body size is a less important factor for male fitness, while for females a large size at maturity probably implies less fitness costs, as large eggs, large fecundity and access to the best spawning sites (Boudaya *et al*., 2008). In many cases, size differences are associated with sexual differences related to the relative distribution of energy for gamete production (Weatherley, 1987). In this study, the size of first sexual maturity (L_{50}) of *D. volitans* was 192.8 mm SL for males and 158.6 mm for females. This result indicates that females reach sexual maturity smaller than males in the coastal waters of Côte d'Ivoire. Our data is comparable to that reported by Machado *et al*.. (2002) in the northern coast of Sao Paulo, Brazil (173.8 mm for females and 192.5 mm for males). The differences can be attributed to differential growth, ecological conditions, particularly temperature, that stimulate sexual maturation (Uçkun-İlhan and Toğulga, 2007) human activities such as overfishing and the distribution of energy for gamete production (Poulet, 2004;Toguyeni, 1997) and the methods used (Maggio *et al.*, 2018). From the monthly variation of both GSI and percentages of maturity stages, it can be assumed that the flying gurnard is probably an asynchronous spawner, spawning twice during a relatively long reproductively active period, from May to August and from November to February. This is confirmed by the presence of all stages of oocyte development throughout the year and the absence of inactive or resting periods. The spawning started two months before the onset of upwelling seasons (July–October and January–February) and continues until the end of these periods in waters of Côte d'Ivoire. According to Morlière and Rébert (1972) this upwelling season is marked by the availability of the resource, assessed by the highest abundances of nutrients and chlorophyll-*a*. After the spawning season, males of the flying gurnard were dominant over females. The sudden decline in frequency after February and September probably suggests the end of the reproductive season.Our results were compared to those of Machado *et al.*(2002) and Mazza (2019). These authors reported that the maximum spawning period is between November and February in the northern coast of Sao Paulo, Brazil whereas it occurs in summer in the coast of Monaco, France. Dajoz (1971) and İlkyaz *et al*.(2010) consider that the difference in breeding frequency from one biogeographic area to another would probably be due to climatic, dietary, biotic (density, group effect) and a biotic (salinity, chemical composition of hydric factors) factors that are the main factors affecting spawning.

To our knowledge, our analysis provides for the first time an estimation of batch fecundity of the flying gurnard in the Gulf of Guinea. The batch fecundity ranged from 4164 to 112232 oocytes for females ranging 170 to 365 mm in standard length and weights of 93–710.5 g. This fecundity increased strongly with both standard length and body weight. Regarding the fecundity, the flying gurnard could be placed in the category of species that produce a lot of oocytes to sustain their stock. Dadzie *et al*. (2008) attribute this high fecundity to a strategy aimed to maximising offspring survival in species that do not practice parental protection as is the case in *D. volitans*.

CONCLUSION

This study establishes an understanding of some aspects of the reproductive biology of the flying gurnard in waters of Côte d'Ivoire. This species spawned twice during a relatively long reproductively active period, from May to August and from November to February. The observed fecundity and oocyte diameters show that *D. volitans* belongs to the category of species with small eggs and high fecundity. This information will contribute to a scientific basis for future management.

ACKNOWLEDGEMENTS

Our thanks are addressed to the Oceanological Research Centre of Abidjan (Côte d'Ivoire) which, through its financial support, made this work possible. We also thank all the scientific staff of the Department of Living Aquatic Resources for their help.

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