Growth, Mortality, Sexual Maturity and Exploitation Level of the Golden African Snapper (*Lutjanus fulgens*, Lutjanidae) in Ghanaian Waters

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Abstract

The golden African snapper, *Lutjanus fulgens*, is one of the most commercially important demersal species exploited by commercial fishers along the coast of Ghana. Growth and mortality as well as aspects of reproduction of *L. fulgens* were studied to contribute to the paucity of biological information on the species in Ghanaian waters. Samples were collected along the coast of Ghana from September 2018 to August 2019. Total lengths of *L. fulgens* sampled ranged between 16.2 and 45.6 cm. Length-weight relationship of the species showed isometric growth pattern. The asymptotic length (L_∞), growth coefficient (K) and age at zero length (t_0) for *L. fulgens* were estimated as 51.09 cm, 0.47 yr^{-1} and -0.301yr respectively. Total (*Z*), fishing (*F*) and natural (*M*) mortality rates of *L. fulgens* were estimated at 2.69 yr^{-1}, 1.91 yr^{-1} and 0.78 yr^{-1} respectively. The length-at-first capture (L_c) = 31.51 cm, was slightly lower than the length-at-first maturity (L_m) = 33.7 cm for females. The exploitation ratio (E = 0.71) of the stocks in Ghanaian waters was above the optimal exploitation levels. Peak spawning period was observed from July to September. Mean fecundity was estimated to be 77,833 ± 13,012 eggs (mean ± SE). There was no significant difference observed in the sex ratio between males and females. The findings suggest the stocks are under high fishing pressure and so it is recommended that to avoid exploiting the spawning biomass, closed season could be observed during the spawning periods.

Introduction

Snappers are demersal fish species of high commercial value in Ghana. They belong to the family Lutjanidae. There are about five different species belonging to the family which occur in Ghanaian waters. The most common amongst them are the Golden African snappers, *Lutjanus fulgens* (Valenciennes, 1830) (Kwei & Ofori-Adu, 2005). The species is also distributed along the West African coast, primarily between Nigeria and Senegal, and at Cape Verde Islands (Allen, 1985).

According to Nikolioudakis et al. (2019), the estimated total biomass of valuable demersal groups in Ghana's waters was 14,959 tonnes of which snappers contributed 6.86% (1,026 tonnes). The catch rate of snappers was 4.9 kg/h, the highest in the outer shelf (51 - 100 m) in Ghanaian waters (Mehl et al., 2006; Toresen et al., 2016; Nikolioudakis et al., 2019). These are actively and locally exploited in Ghanaian waters by both artisanal and semi-industrial fisheries and contributed about 1.08% of total catch and 2.90% of demersal landings in 2009 (Fisheries Commission, 2018). There is the predominance of hook-based fishing gears in the exploitation of *L. fulgens* with a few caught in bottom trawls in Ghana.

Due to the significant contributions of *L. fulgens* to Ghanaian fisheries, there is the need to know the biological characteristics of the species to provide baseline information to understand the dynamics of the stock. It is against this backdrop that this study aimed to assess the status of the *L. fulgens* in Ghanaian waters through the study of variables related to its population and reproductive characteristics, such as growth and mortality parameters, sexual maturity and exploitation rate.

Materials and methods

Study area

The study was conducted along the coast of Ghana at three fish landing sites (Fig. 1). These sites were: Tema Fishing Harbour in the Greater Accra Region (5°38'39.43"N, 0°0'58.55"E), Elmina fish landing quay in the Central Region (05°4'57.14"N, 1°21'2.29"W) and Albert Bosomtwi-Sam Fishing Harbour in the Western Region (4°56'28.91"N,

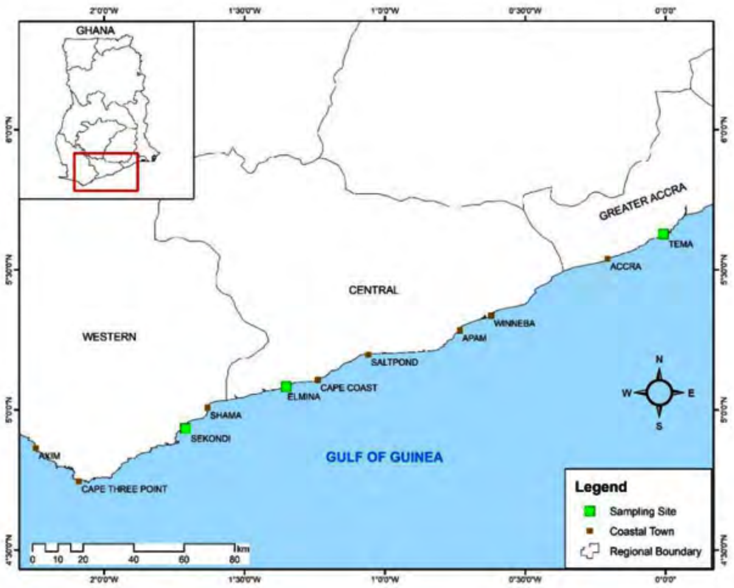

Fig. 1. Fish sampling locations along the coast of Ghana

1°42'29.35"W). These sites represent the major fish markets where artisanal catches of *L. fulgens* are landed along the coastline of Ghana. Hook and line and bottom trawls are the main gears used in the exploitation of *L. fulgens* by the local fishers.

Sample collection

Fish samples were collected monthly from landings of artisanal fishermen between September, 2018 and June, 2019 at the 3 landing sites except in May, 2019 due to an observed closed season. Specimens collected were put on ice and carried to the laboratory for sorting and identification using Schneider (1990). In July and August 2019, samples were collected onboard the Research Vessel, Dr. Fridtjof Nansen from bottom trawls. The *L. fulgens* specimens were collected when they occurred in the haul at various stations during the survey. Total lengths (TL) were measured to the nearest 0.1 cm using a fish measuring board. Body weight (BW) of each specimen was also taken using balance (Model: Ohaus Ranger 7000) to the nearest 0.01g.

The length-weight relationship of *L. fulgens* was determined using the equation:

$$BW = aTL^b, \text{ (Le Cren, 1951)}$$

where

W is the total body weight (g) and TL is the fish total length (cm), *a* is the intercept of the regression and *b* is the growth coefficient. The *b* value from the length-weight equation was tested using the Student's t-test statistical analysis to ascertain the growth pattern of the population.

The sex of each specimen was determined macroscopically by examining the gonads. The gonads were weighed to the nearest 0.01g and graded on a scale adopted by Holden & Raitt (1974) as follows: I- Immature, II- Maturing virgin and recovering spent, III- Ripening, IV- Ripe, V- Spent. Gonadosomatic index (*GSI*) was determined for males and females to assist in determination of spawning period. Fecundity for the various specimens was calculated using the formula by Bagenal (1978):

$$F = nG/g$$

where

F = fecundity, n = number of eggs in the subsample, G = total weight of the ovaries, g = weight of the subsample in the same unit.

The monthly length data collected was analysed using the R package TropFishR (Mildenberger et al., 2017) to assess the growth and mortality parameters following the steps outlined in the vignette on TropFishR ELEFAN functions. TropFishR has traditional and updated versions of the Electronic LEngth

Frequency ANalysis (ELEFAN) method (Pauly, 1980), used in growth parameter estimation, with new optimization techniques (Mildenberger et al., 2017) and a complete set of methods for fisheries analysis with Length Frequency data. Growth rate (K), asymptotic length (L_∞) and the growth performance index (ϕ') of the species was estimated using the von Bertalanffy Growth Function (VBGF). The length-converted catch curve derived was used to estimate the total mortality rate (Z). Natural mortality rate (M) was calculated using the empirical formula as suggested by Pauly (1983):

$$\log (M) = -0.0066 - 0.279 \log (L_\infty) + 0.6543 \log K + 0.4634 \log (T)$$

where

M = natural mortality, L_∞ is the asymptotic length of the fish, K is the growth coefficient, and T is the annual mean temperature. The exploitation ratio (E) was calculated by the quotient between fishing (F) and total mortality:

$$E = F/Z \text{ (Pauly, 1984).}$$

Results

Trawl stations along the coast of Ghana where samples of *L. fulgens* were captured during the Fridtjof Nansen survey are shown in Fig. 2. Denser populations of *L. fulgens* were observed in the west and central coast as compared to a sparse distribution in the east coast.

The sample size of *L. fulgens* obtained along the coast of Ghana during the study period were 906 specimens comprising of 425 males, 443 females, 38 indeterminate sexes. The total lengths ranged from 16.2 to 45.6 cm with a

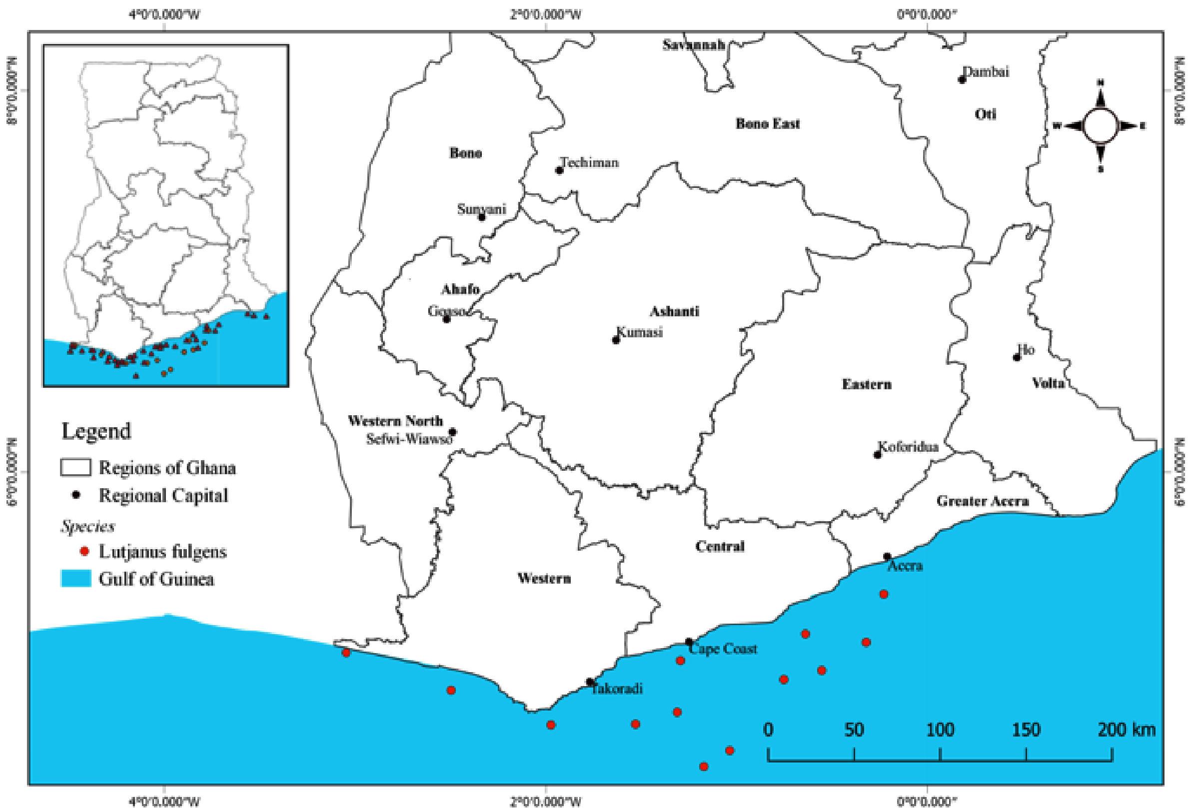

Fig. 2 Distribution of *L. fulgens* at the various stations of catch along the coast of Ghana during the RV Dr. Fridtjof Nansen survey in July and August 2019

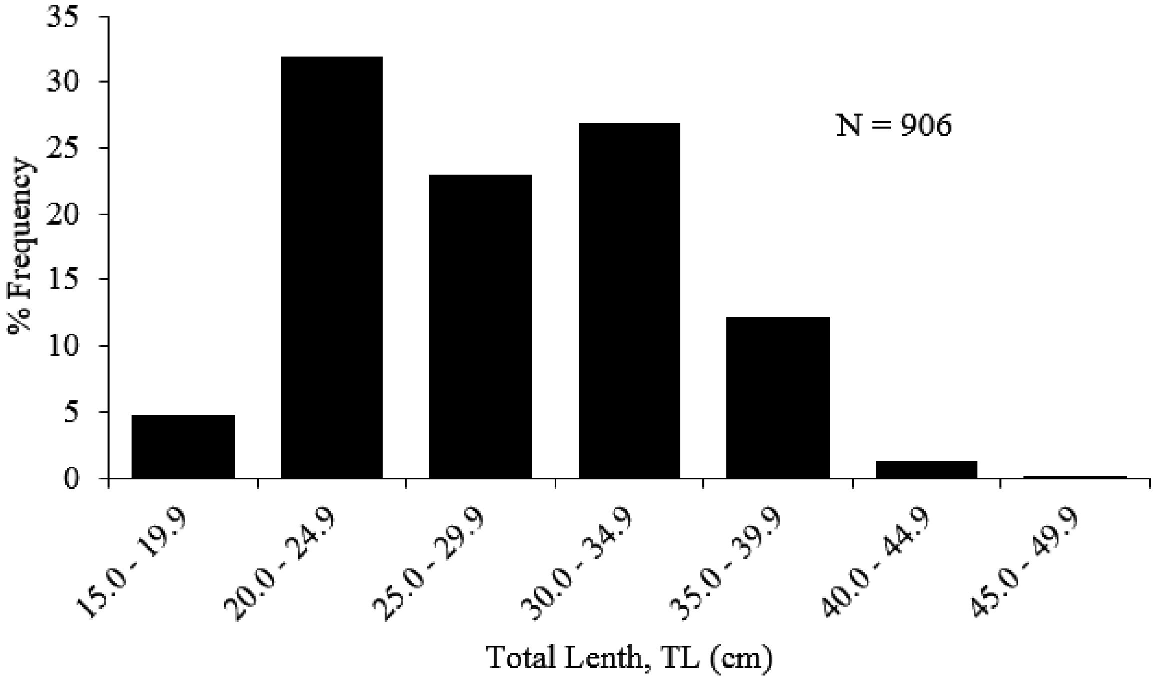

Fig. 3 Length-frequency distribution of *L. fulgens* along the coast of Ghana

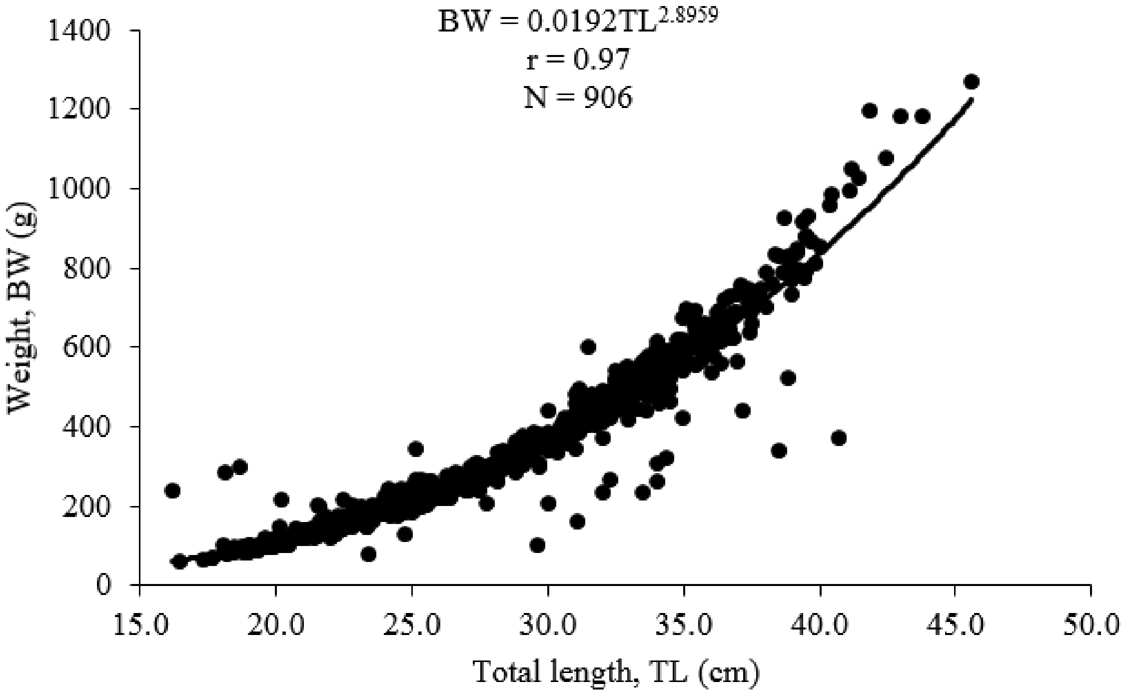

Fig. 4 Length-weight relationship of *L. fulgens* along the Coast of Ghana

modal length class of 20.0 – 24.9 cm (Fig. 3). The weight recorded ranged between 58.0 and 1271.8 g (Fig. 4).

The length-weight relationship of *L. fulgens* population was described by the equation:

$$BW = 0.0192\ TL_{2.8959}\ (r = 0.97)$$

where

BW = body weight in grams and TL = total length in cm (Fig. 4). The power of the equation (b = 2.8959) was not significantly different (Student's t-test = 126.3194; $p<0.05$) from the hypothetical value (b = 3.0).

Estimates of the growth and mortality

TABLE 1

Growth and mortality parameters of *L. fulgens* along the coast of Ghana (September, 2018 – August, 2019)

Growth and Mortality parameters	*Lutjanus fulgens*
Asymptotic length (L_∞)	51.09 cm
Maximum observed length (L_{max})	45.6 cm
Longevity (t_{max})	6.41yr
Theoretical age at length, 0 (t_0)	-0.30yr
Growth constant (K)	0.47yr^{-1}
Length at first capture (L_c)	31.51cm
Length at first sexual maturity (L_m)	33 cm
Age at first capture (t_c)	2.0 yr
Total mortality (Z)	2.69 yr^{-1}
Natural mortality (M)	0.78 yr^{-1}
Fishing mortality (F)	1.91 yr^{-1}
Exploitation ratio (E)	0.71

parameters from the length-frequency data are shown in Table 1.

The VBGF describing the growth of *L. fulgens* along the coast of Ghana are as follows:

$$L_t = 51.09\{1 - \exp[-0.47(t + 0.301)]\} \text{ (Fig. 5).}$$

The maximum observed length of *L. fulgens* was 45.6 cm and the corresponding age was estimated as 4.4 years. The length at first capture (L_c) for *L. fulgens* was estimated at 31.51 cm, which corresponds to an age (t_c) of 2 years (Table 1).

The total mortality (Z), natural mortality (M), and fishing mortality (F) of *L. fulgens* were estimated as 2.69 yr^{-1}, 0.78 yr^{-1} and 1.91 yr^{-1} respectively with the current exploitation ratio determined to be 0.71 (Table 1).

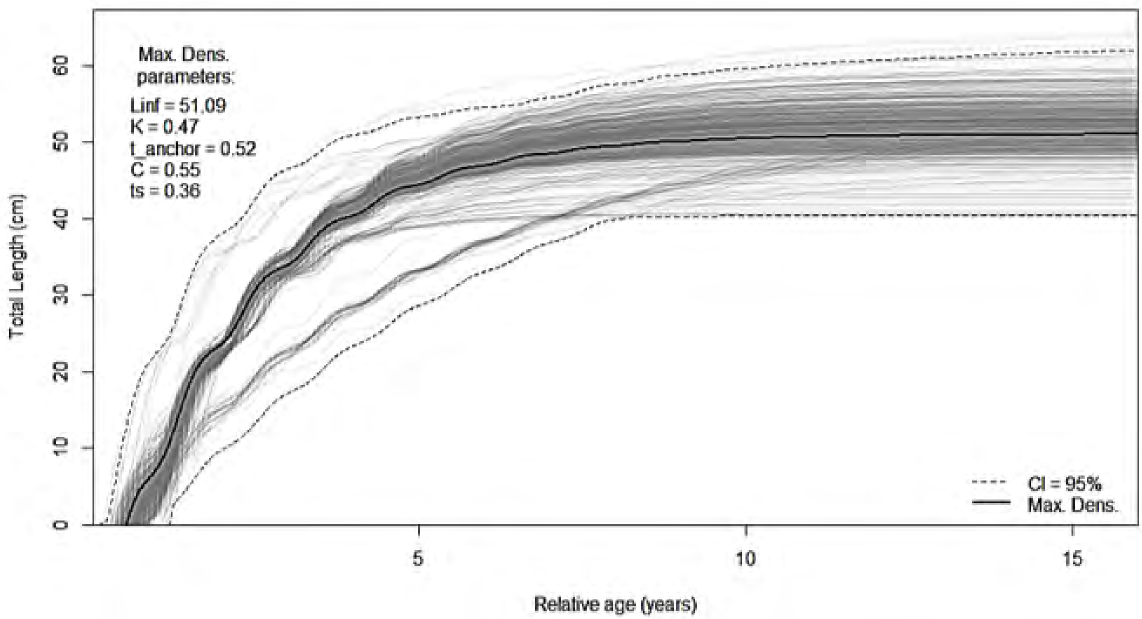

Fig. 5 von Bertalanffy growth curve of *L. fulgens* along the coast of Ghana

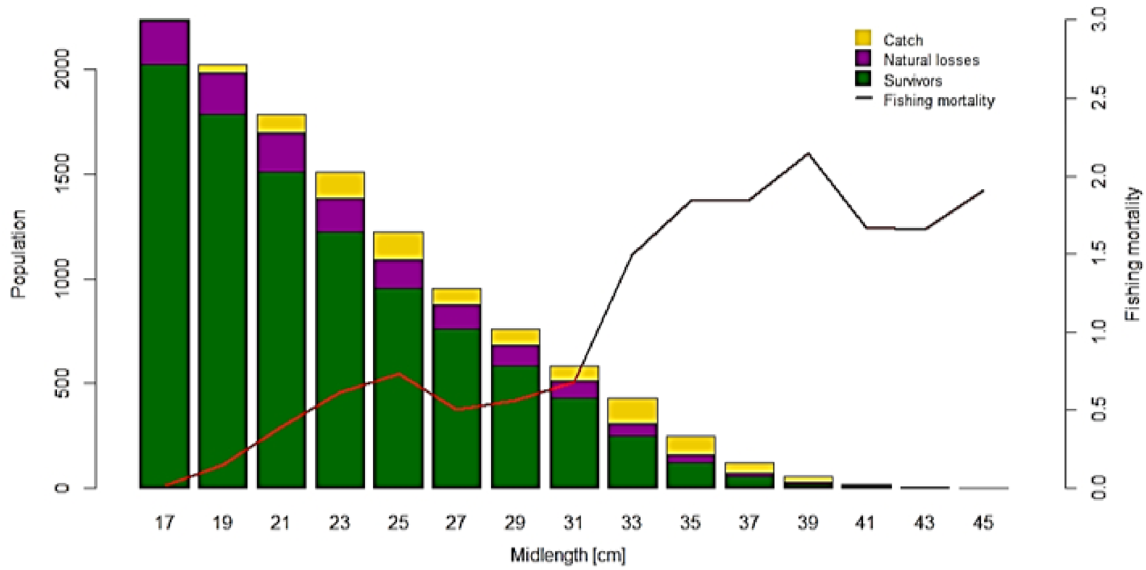

Fig. 6 Length structured VPA indicating the catch, natural losses, survivors and fishing mortality of *L. fulgens*

In Figure 6, the input parameters used for length structured VPA were L_∞ of 51.09, K of 0.47 and M of 0.78, *a* as 0.0192 and *b* as 2.8959 from length-weight relationship of the species. High fishing mortality in larger length groups was observed as compared to the smaller length groups. Mortality in the population due to natural causes were high in fishes less than 19 cm. Fishing mortality started at 19 cm midlength and continued to increase to midlength class of 39 cm (Fig. 6).

Of the 906 specimens of *L. fulgens* sampled, 46.9% comprised of males; 48.9% females and 4.2% indeterminate sex. The monthly sex ratios of *L. fulgens* indicated that the males dominated the population apart from the months of January, February and August, 2019. Conversely, the overall sex ratio (M:F) of *L. fulgens* was in favour of the females with a ratio of 1:1.04 but did not differ significantly from the normal expected ratio of 1:1 of fish populations (Table 2).

TABLE 2

Sex ratios of *L. fulgens* along the coast of Ghana as estimated from September 2018 to August 2019

Month	Total number	No. of males	No. of females	χ2	Sex ratio	
					M:F	ρ = .05
September	9	5	4	0.111	1.3:1	NS
October**	-	-	-		-	
November	139	81	58	0.331	1.4:1	NS
December	144	82	62	2.777	1.3:1	NS
January	125	44	81	10.952	1:1.84	S
February	143	63	80	2.021	1:1.27	NS
March	55	28	27	0.018	1:1	NS
April	108	66	42	5.333	1.6:1	S
May***	-	-	-		-	
June	44	22	20	0.095	1.1:1	NS
July	19	11	8	0.474	1.4:1	NS
August	84	23	61	17.190	1:2.65	S
Total	868	425	443	0.373	1:1.04*	NS

*indicates overall monthly sex ratio, S = significant and NS = not significant, *df* = 1
** data not available

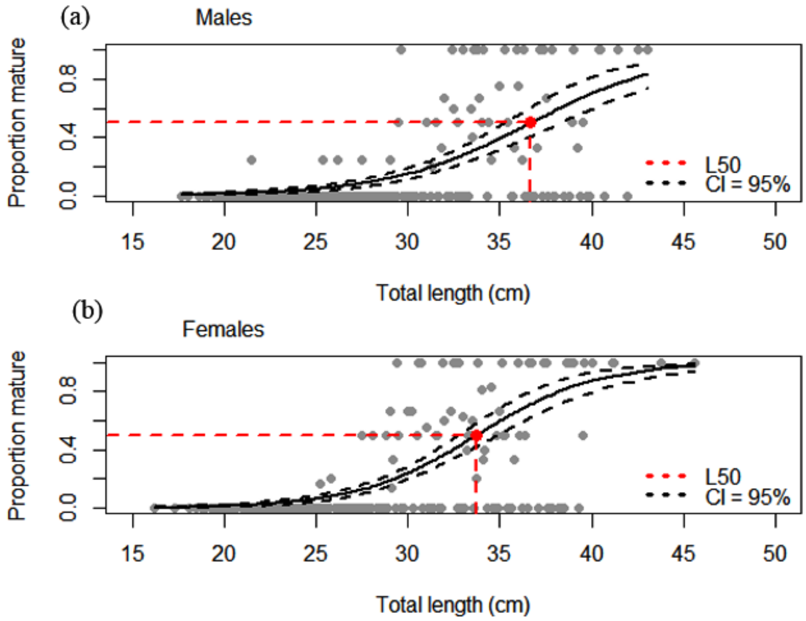

Fig. 7 Length at first sexual maturity for: (a) male and (b) female *L. fulgens*

The mean size at first sexual maturity (L_{50}) was estimated for both sexes by fitting the logistic function to the proportion of mature fish in 2 cm (*L*F) size categories. The mean size at first sexual maturity was taken as the size at which 50% of individuals were mature. From the current study it was gathered that male *L. fulgens* tend to mature at 36.7 cm (Fig. 7a) while the females do so at 33.7 cm (Fig. 7b).

There were distinct monthly variations in the GSI of both male and female *L. fulgens* (Fig. 8). This variation was significantly different $t(8) = 2.31$, $p = 0.002$ with females ($M = 1.19$, $SD = 0.06$) attaining higher values than males ($M = 0.62$, $SD = 0.04$) where *M* and *SD* stands for mean and standard deviation respectively. Four peaks were observed in the trend of GSI of female *L. fulgens* (September and November 2018, March and July 2019). The GSI of the males peaked in September and July. The pattern of GSI for the females was quite similar to that of the males. Of the peaks

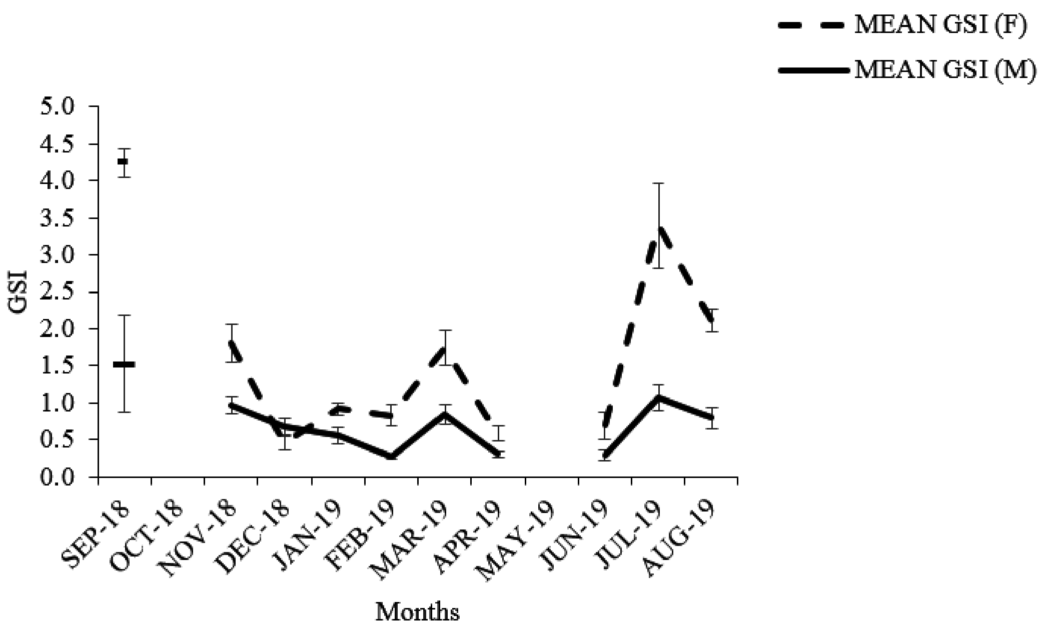

Fig. 8 Monthly mean Gonadosomatic index of males and females *L. fulgens* during September, 2018 to August, 2019 (vertical bars represent standard errors)

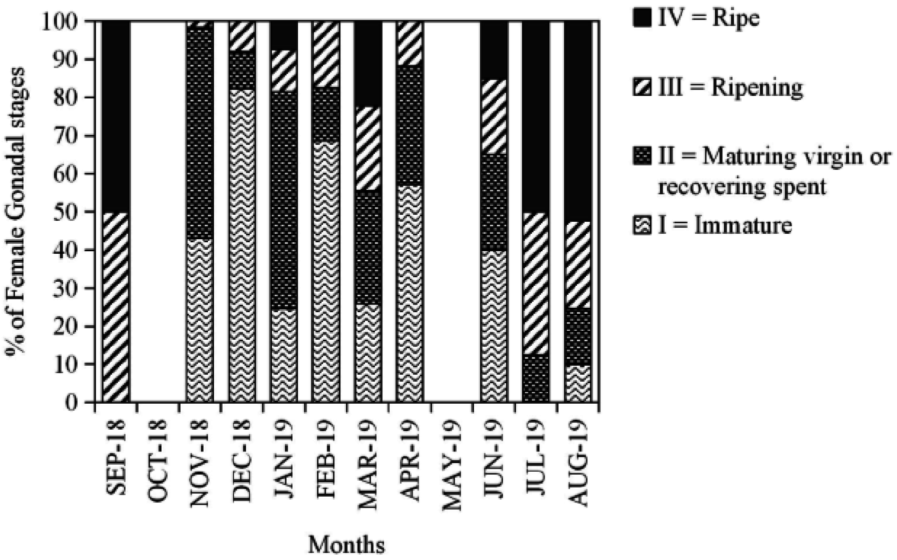

Fig. 9 Monthly variation for maturity stages for female *L. fulgens*

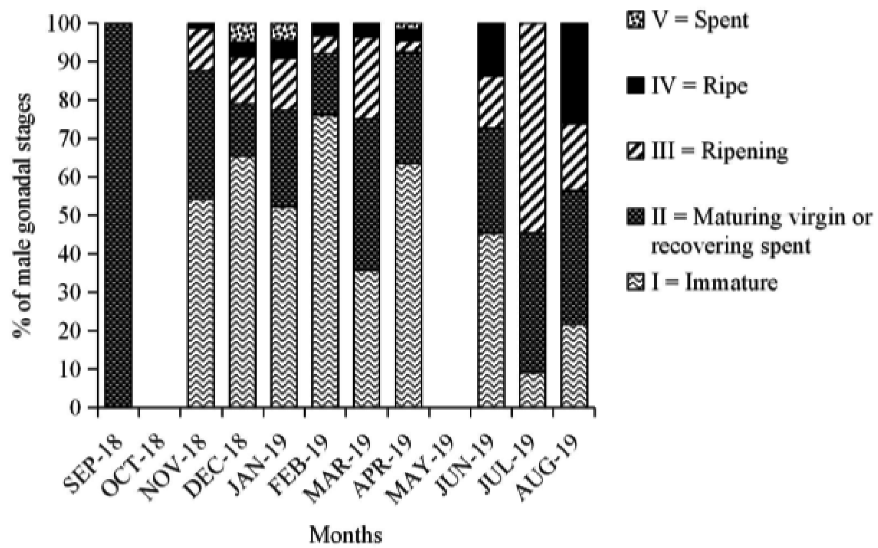

Fig. 10 Monthly variation for maturity stages for male *L. fulgens*

identified, the highest occurred in September 2018 and July 2019 in both sexes.

Gravid and ripe females were recorded in all the months with their peak occurrence observed in September (Fig. 9). Lesser proportions of maturing virgins were observed from July to August, and with September showing mainly ripening and ripe females. This further suggests a spawning window from July to September.

Six stages of gonadal development were observed in male and female *L. fulgens*. Females with ripe eggs (Stage IV) were recorded in almost all the months except in November, December, February and April with their peak occurrence observed in July to September. About 50% of all females encountered within those months were gravid with ripe eggs. This suggests a reproductive window from July to September (Fig. 9). Males with ripe gonads occurred less during the entire period, however, about 14% and 26% were present in June and August 2019, respectively (Fig. 10). Males with spent gonads (Stage V) occurred only in December, January and April representing 5%, 5% and 2% respectively. Stage III males and females occurred throughout the period with the highest proportion represented in

July for males (55%) and in September for the females (50%). Stages I and II males and females were present in all the months with higher proportions occurring in the males. Lesser proportions were observed from July to September especially in the females.

The number of ripe eggs of *L. fulgens* ranged from 10,136 to 219,994 eggs with a mean of 77,833 ± 13,012 eggs (mean ± SE) based on 30 ovaries of specimens with total length ranging from 29.0 - 43.8 cm and weight, 350.6 – 1,179.2 g. The fecundity of *L. fulgens* was related to the total length, body weight and gonad weight of individual fish with ripe ovaries. The relationship between fecundity (F) and total length (TL) of *L. fulgens* was represented as:

$$F = 7441.8\ TL - 175388\ (r = 0.28).$$

And the relationship between fecundity and body weight (BW) was as follows:

$$F = 168.15\ BW - 7843.4\ (r = 0.42).$$

Again, the relationship between fecundity and gonad weight (GW) was represented as:

$$F = 7584.7GW - 33821\ (r = 0.73).$$

It can be inferred that fecundity increases more with weight than with length of the fish. The highest correlation co-efficient of (r = 0.73) was observed between fecundity and gonad weight indicating a high degree of relationship between these two variables. This suggests that gonad weight proves to be the better index of fecundity in *L. fulgens*.

Discussion

L. fulgens were densely populated in the west and central coast of Ghana as compared to the east coast (Figure 2). This could be attributed to the continental shelf along the west coast up to 50 NM as compared to the east of less than 20 NM (Staby et al., 2017). The continental shelf is characterized by an enhanced productivity and biological activity due to the input of nutrients from rivers such as the Ankobra and Pra, and more importantly, from the transfer of nutrient-rich deep ocean waters during upwelling (Wollast, 2002). Thus, the wider the shelf, the great the area of shallow water and higher the productivity. This therefore, could explain the high numbers of *L. fulgens* in the western part of the coast of Ghana.

A unimodal size class was observed for *L. fulgens* in this study, 20.0 – 24.9 cm. This modal class was followed by yet another modal class of 30.0 – 34.9 cm. This observation could be true because the fishers tend to fish for larger sizes since the fishes are sold by their sizes; the bigger the fish, the higher its price. It is known from pers. comm. (fisherfolks) that there is the predominance of hook-based fishing gears for the exploitation of *Lutjanus fulgens*, with a few caught in bottom trawls. This fishing gear is a highly selective gear in the exploitation of demersal species mostly, the seabreams such as *Dentex gibossus*, *Pagrus caeruleostictus*, *Dentex canariensis*; and snappers of which include, *Lutjanus dentatus*, *Lethrinus spp.* and *L. fulgens*. The length-frequencies of male and female *L. fulgens* show that larger fish are more likely to be females (Amador, 2020). Various studies on lutjanids have reported similar observations of larger sizes dominated by female fishes (Hay et al., 2005; Almamari et al., 2017; Pradeep, 2018).

The relationship between total length and body weight of *L. fulgens* along the coast of Ghana was described by the equation

$$BW = 0.0192TL^{2.8959}\ (r = 0.97)$$

exhibiting isometric growth. The measured *b* value was within the expected value for most fishes (Froese, 2006) and in accordance with other members of the family Lutjanidae (*Lutjanus jocu*, *Lutjanus synagris*, *Lutjanus apodus*, and *Lutjanus analis*) in the Gulf of Salamanca, Colombia and *Lutjanus fulviflamma* in the Northern Persian Gulf (Garcia et al., 2000; Razi & Noori, 2018). Other reports had established that, length-weight relationships play major role in assessing the biology of fish fauna and it is helpful in estimating the weight of fish corresponding to a given length. According to Previero et al. (2011), length-weight relationships have diverse applications, viz. for studies on fish biology, physiology, ecology and fisheries assessment. This is because size is generally more biologically relevant than age; consequently, variability in size has important implications for diverse aspects of fisheries science and population dynamics.

L. fulgens is known only from the West African coast primarily in the Gulf of Guinea (Carpenter & De Angelis, 2016), and it is known to grow to a maximum size of 60 cm but most common at 50 cm (Allen, 1985). The growth parameters, L_∞ and L_{max} derived from the length-based estimates of *L. fulgens* in this study were: 51.09 cm and 45.6 cm respectively which agree with the aforementioned size. According to Shimose & Nanami (2014), maximum body sizes vary among *Lutjanus* species indicating that there are smaller sized species. For example, *Lutjanus cyanopterus* grows up to a total length of 160 cm whilst *Lutjanus biguttatus* grows up to 20 cm in total length. Longevity was estimated at 6.59 years, with a K value of 0.47. Total (Z), fishing (F) and natural (M) mortality coefficients were estimated as: 2.69, 1.91 and 0.78 yr^{-1} respectively in this study; whereas Z, F and M derived for *Lutjanus fulviflamma* from length converted catch-curve and Pauly's empirical formula were, 1.97, 0.27 and 1.70 yr^{-1} respectively as reported by Kaunda-Arara & Ntiba (2001) in Kenya. The growth parameters, L_∞, K and t_0 derived from the length-based estimates of *L. fulviflamma* in Kenya were: 35.0 cm TL, 0.59 and -0.55 years respectively. Comparatively higher values of these parameters were observed for *L. fulgens* in Ghanaian waters. The low fishing mortality together with low exploitation ratio of 0.137, derived for the stock of *L. fulviflamma* in Kenya's nearshore fishery suggests that the stocks are underexploited. However, in this study, exploitation ratio was estimated at 0.71 which indicates overexploitation of the fishery resource. Again, the length virtual population analysis showed an increasing trend of fishing mortality, F, for larger size groups. The reason for this could be attributed to fishers' preference and target large sizes mainly because there is high economic value for larger snappers compared to the smaller size groups. It is therefore not surprising that mortalities for the smaller size group was mainly due to the natural causes. The length-at-first capture (L_c) was estimated at 31.51 cm and is slightly lower than length-at-first maturity (L_m) of 33.7 cm for females *L. fulgens*. This indicates that the species enter the exploitation phase just before attaining sexual maturity.

Being dioecious, populations of *L. fulgens* was not expected to have a sex ratio that differed significantly from 1:1. The overall sex ratio observed for *L. fulgens* did not differ significantly from a 1:1 ratio. However, slightly more males than females were observed in most months (Amador, 2020) which corroborates findings in other fishing grounds such as in Bermuda and south-eastern USA (Luckhurst et al., 2000; White & Palmer, 2004). Relatively high number of females dominated the catch during spawning periods and this could be a principal factor that might explain the observation that females become most vulnerable to fishery exploitation at spawning grounds.

From this study, it was gathered that female *L. fulgens* tend to mature at 33.7 cm while the males do so at 36.7 cm. On the contrary, White & Palmer (2004) and Almamari et al. (2017) reported that male snappers tend to mature earlier than females, a common life history trait found in lutjanid species. The sexual maturity records obtained were, however, consistent with reports for other lutjanid species; *Lutjanus jocu* in the tropical western South Atlantic (Freitas et al., 2011) and *Lutjanus goreensis* in Nigeria (Fakoya et al., 2015). For some lutjanid species, females have been shown to grow larger than males as reported by Grandcourt et al. (2006) in the Southern Arabian Gulf, and this was true for *L. fulgens* in Ghanaian waters. In contrast, other studies in Okinawa, Japan have also shown that males grow larger than females (Nanami et al., 2010). Thus, sex differences in growth exist among species.

It was observed that GSI of the females of *L. fulgens* were generally higher than that of the males. Shimose & Nanami (2014) in their study found that individual GSI of females often exceeded 6.0 and even more during the spawning season while that of males did not exceed 5.0 even in the peak spawning months. This finding could be attributed to perhaps smaller testes of male blacktail snapper being sufficient for short spawning days and the ability of males to recover their testicular size until the next spawning. According to Rajesh et al. (2015), trophic enrichment during the upwelling season probably provides a favourable reproductive regime for the spawning of most fishes. Upwelling activities replenish seawater nutrients leading to better productivity offering enough food for the larvae, giving them a better chance to grow faster and pass quickly through critical stages (Koranteng, 1998). It may not wholly be attributed to the spawning seasonal pattern of *L. fulgens* since there were gaps in the monthly data collection. In Ghana, the major upwelling period spans from June to September. It is apparent from the GSI pattern and monthly variation in gonadal stages that spawning takes place during the major upwelling season from June to September. According to Moncrief et al. (2018), GSI patterns that defined the spawning season for Vermilion snapper ranged from April to September in the North Central Gulf of Mexico. Shimose & Nanami (2014) also reported same for the spawning season of blacktail snapper around the Yaeyama Islands, Okinawa, Japan.

Observations from studies conducted on fecundity of snappers and the relatively long spawning periods indicate that a relatively high fecundity could be expected. Fecundity ranged between 10,136 to 219,994 and the average number of eggs for *L. fulgens* was 77,833 ± 13,012 (mean ± SE) eggs (n = 30). This finding is relatively similar to that of other snappers worldwide. The batch fecundity of the Brazilian snapper, *L. alexandrei* off the northern coast of Pernambuco, Brazil ranged between 33,990 and 323,738 eggs (Fernandes et al., 2012). The average number of eggs for *L. quinquelineatus* was 389,880 eggs (n = 34) as reported by Baker et al. (2017) from the Red Sea off Hurghada, Egypt. Again, it was observed that the number of ripe eggs of the individual females were at variance with one another. This was observed in the snapper, *Chrysophrys auratus* where fecundity varies widely for fish of the same length (Crossland, 1977) and reported by other workers for many species of fish (Devlaming et al., 1982; Arizi et al., 2015). Much of this variation was probably because of real differences in fecundity, but may also be due to the stage of developmental maturity of the ovary at sampling. Thus, the exact timing of sampling is likely to be the most critical factor influencing the accuracy of fecundity determinations for serial spawning fishes (Crossland, 1977).

Based on these findings, the study concludes that *L. fulgens* off the coast of Ghana is vulnerable to overfishing based on the exploitation ratio determined. This is possible because the stocks appear to be under high fishing pressure that suggests immediate reduction in fishing effort in order not to collapse the lutjanids fishery. It is also advisable to avoid exploiting the spawning biomass by observing closed seasons during the spawning periods ideally from July to September. In addition, the estimated population parameters for *L. fulgens* could serve as a baseline information for fishery managers to implement management strategies suitable for sustainable utilization of the fishery resource in Ghanaian waters.

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