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Spawning, length-growth, mortality and exploitation rate of *Galeoides decadactylus* exploited from the artisanal fisheries of Sierra Leone

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Abstract
865 specimens of *Galeoides decadactylus* were analysed for spawning, length-growth, mortality and exploitation rates in May-October 2020, to support with management information. Gonads were macroscopically assessed and total length-frequencies analysed from growth models in FiSAT II software. Gonadosomatic Index of the assessed stock peaked in October alongside Hepatosomatic Index, and attained first sexual maturity at lengths 19.8 cm (female) and 25.7 cm (male,). Infinity length (L_∞) was 43.3 cm, growth rate (K), 0.34 yr^{-1}), theoretical age (t_0), -0.7 years, lifespan (t_{max}), 8.1 years and growth exponent (b), 2.78. Total (Z), natural (M) and fishing mortality (F) rates gave 1.58 $year^{-1}$, 0.77 $year^{-1}$ and 0.81 $year^{-1}$ respectively, whereas the current exploitation rate ($E_{current}$) was 0.51 $year^{-1}$. The optimum fishing effort (F_{opt}) and fishing limit (F_{limit}) were 0.31 $year^{-1}$ and 0.51 $year^{-1}$ respectively. Results implied occurrence of major spawning in October, negative allometric growth, short lifespan and high fishing pressure on the stock. Recalibration of management measures is advised.

Keywords: Growth, longevity, mortality, spawning, stock

1. Introduction
Galeoides decadactylus (Bloch) belongs to the Polynemidae family, and is commonly known as the Lesser African Threadfin. The species is most distributed on the West Coast of Africa from Morocco to Angola, and rarely exists in the northern and southern African Coasts [1-3]. It is a typical marine species and occurs at depths ranging from 10-70 m [2].

Galeoides decadactylus is a critically acclaimed natural capital that contributes significantly to local diets and economy in Sierra Leone. The fish is among the ten most commercially important demersal finfish species in Sierra Leone and contribute about 48.5% (0-30 m), 10.9% (31-50 m), 37.1% (51-100 m) and 3.5% (101-200 m) depth zones [4].

Knowledge about the biology of fish stocks is eminent for efficient management of the resources [5-6]. Sex ratio, size at sexual maturity and spawning in fish species inform of the reproductive potential and periods of reproduction that are particularly relevant in identifying unit stocks as well as regulatory measures for replenishing the spawning biomass of a fish stock [5, 7, 8]. Studies on Growth, mortality and exploitation rates inform of the status of fish stocks as regards size, fishing pressure and exploitation limit [3, 6, 9]. Besides, natural mortality provides apt indication of a decline in individuals of a stock through predation, age and diseases [10]. Moreover, the length-weight regression coefficient, b=3 implies that the fish maintains its shape as it grows (isometric growth); b>3 implies a proportional growth rate between length and weight (Positive allometric growth), and the reverse is true when b<3 [11-12].

The present study aimed at assessing the stock of *Galeoides decadactylus* by evaluating the spawning and length at first sexual maturity (L_m), length-growth, mortality and current exploitation level in the Artisanal Fisheries of Sierra Leone. The study specifically addressed the following questions: What type of spawner was the species and when did major spawning occur? Was there a similarity in length at sexual maturity between the male and female specimens of the assessed stock? What was the growth pattern of the species? Did length-growth obey previous growth model?

What was the status of the stock as regards fishing pressure and current exploitation level? Despite the limited sampling period for this study, the information provided could guide management decisions on rational exploitation for sustainable production of the stock of *G. decadactylus* in Sierra Leone.

2. Materials and Methods
2.1. Sampling Site
Sierra Leone is geographically located between the latitude 7°10′N and longitude 10°14′W on the west coast of Africa and bordered by Guinea in the North and Liberia in the South, and occupies a total land area of about 71 740 km^2 [13]. The exclusion zone (EEZ) has an area of about 155 700 km^2 [6]. There are two main climatic seasons, the rainy season that extends from May-October and the dry season that starts in November and ends in April [14]. Figure 1 shows Tombo wharf in the Western Area Peninsular where data were accessed during this study.

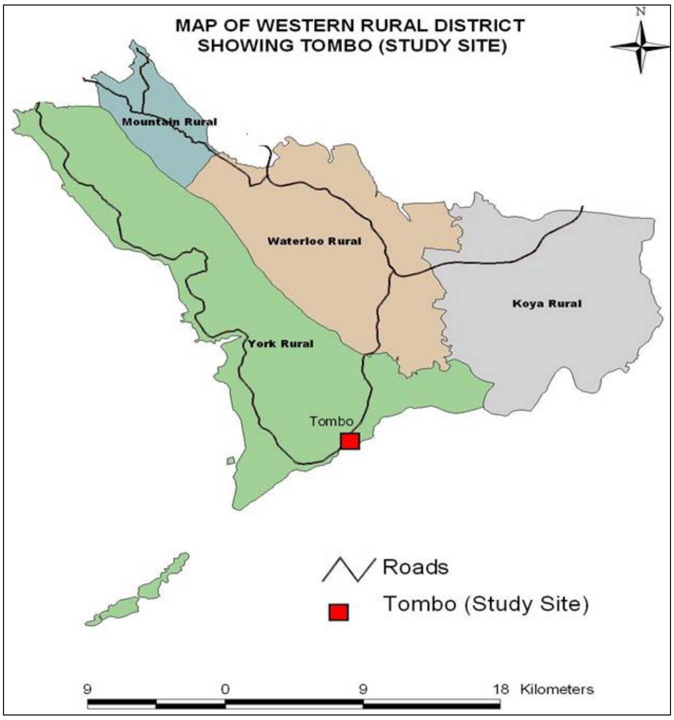

Fig 1: Data Collection Site for *G. decadactylus* in Sierra Leone

2.2. Sampling
2.2.1. Design of the study
The study targeted five (5) artisanal fishing boats from which fresh fish samples were purchased. Specimens were collected in the first week of every month from May to October, 2020 and a simple random sampling technique was employed for collecting specimen from the target boats. A total of 865 specimens were altogether collected and analysed for length-growth and mortality parameters, and only 846 specimens were analysed for spawning characteristics including sex ratio and length at maturity (L_m).

2.2.2. Estimation of Spawning Indicators
Difference in the physical appearance of the sex organs (Colour, texture and mass) and the genital papilla (two openings for male and three openings for females) of specimens were used as indicators of male and female sexes. The percentage sex composition was then calculated using the relation [15]:

$$\% \text{ sex composition} = n/N * 100 \quad (1)$$

Where,
n = number of males or females;
N = total sample.

Also, individual specimens were dissected and liver and gonad removed and weighed for determination of the spawning indices such as hepatosomatic index (HSI) and gonadosomatic index (GSI) respectively. These were calculated using the following relationships [16]:

Hepatosomatic Index

$$(\text{HIS}) = \text{Liver weight/body weight x } 100 \quad (2)$$

Whereas,
Gonadosomatic Index

$$(\text{GSI}) = \text{Gonad weight/Body weight x } 100 \quad (3)$$

Moreover, mature gonads (stages 3-5) were pooled against corresponding total lengths to obtain variations in their percentages for different length groups, and the logistic regression model for sexual maturity (length at which 50% of specimens of the study species were mature) was expressed by the relation:

$$P = \frac{1}{1+Exp^{-(b_2 - b_1 * x)}} \quad (4)$$

This function was rearranged to the log form:

$$\text{Ln}((1-p)/p) = -b_2 + b_1 * x \quad (5)$$

Where
'P' = estimated probability of 50% specimens maturing,
x = Midlength; 'b_2' and 'b_1' were logistic regression parameters (at 95% CL) wherein
b_2 = intercept and
b_1 = slope of the function.

2.2.3. Estimating Parameters of Growth, Mortality and Exploitation Rate
Measurement of total length and fresh body weight of *G. decadactylus* were completed using fish measuring board and digital top-pan balance (Model: ADAM-ACBPlus600H) to the nearest 0.1 cm and 0.1 g respectively.
The length-weight relationship followed the least square regression method by [11-12] thus:

$$W = aL^b \quad (4)$$

Where,
a = intercept, and
b = regression coefficient/ growth constant.

The correlation coefficient (r) was estimated using method by [15] thus:

$$r = \text{SQRT}(R^2) \quad (5)$$

Where,
R^2 = Regression Coefficient of determination and
SQRT = Square Roots.

Also, the monthly length data were pooled into length-frequencies, and estimation of the infinity length (L_∞) and Z/K ratio, growth rate (K), instantaneous total mortality (Z) and instantaneous natural mortality (M) rates followed methods fitted in the FiSAT II software for PCs [17].
The theoretical age (t_0) and lifespan (t_{max}) of *G. decadactylus* were estimated from the relations:

$$Log_{10}(-t_0) = -0.392 - 0.275Log_{10}(L\infty) - 1.038Log_{10}K \quad (6)$$

[18], and

$$t_{max} = (2.9957/K) + t_0 \quad (7)$$ [12]

The fishing mortality rate (F) and exploitation rate (E) were estimated using the relation by [19] thus:

$$F = Z-M \quad (8)$$

And

$$E = F/Z \quad (9)$$

2.2.4. Statistical Analysis

Test of significance (t-test and Chi-square test) and the least-square regression length-weight relationship were completed using methods fitted in Microsoft Excel data analysis package. Also, the real statistics software (xrealstats) for MS Excel (least-square quasi Newton Method) was used to obtain the logistic regression function and its coefficients and probabilities required for the estimation of length at first sexual maturity ($L_{50\%}$) of the study species.
Further, estimation of length-growth and mortality parameters utilized models fitted in FiSAT II software for PCs using pooled length-frequency data.

3. Results

3.1 Spawning Indicators

Figure 2 illustrates the numerical variation in gender of *Galeoides decadactylus*, and male specimens were dominant throughout sampling. The female/male sex ratio (1:1.8) significantly deviated (p>0.05: *p-value* = 0.52; χ^2 = 0.43; df.1; α = 5% significance) from the theoretical ratio of 1:1.

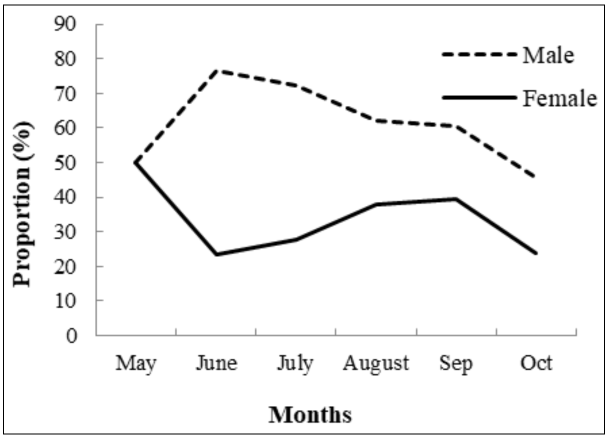

Fig 2: Gender proportions of *Galeoides decadactylus*

Figure 3 shows major peak in Gonadosomatic Index (GSI) and Hepatosomatic Index (HSI) of *Galeoides dacadactylus* in October.

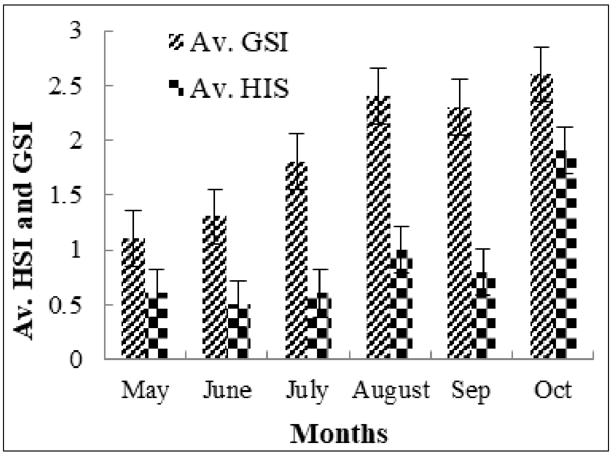

Fig 3: Monthly mean Gonadosomatic (GSI) and Hepatosomatic (HSI) Indices

Figure 4 indicated that females attained first sexual maturity at Mid length, 19.8 cm TL (Range, 18-20.9 cm) and the predicted least square logistic regression model predicted was Ln((1-p)/p) = -12.72 - 0.88 *x (p-value = 0.78; R^2 (N) = 0.07; $\chi^2_{0.05}$ = 0.49; α = 0.05); whereas the males attained sexual maturity at 25.7 cm TL (Range, 24-26.9 cm) with a predicted least square logistic regression model being Ln((1-p)/p) = -8.94- 0.56 *x (P-value = 0.27; R^2 (N) = 0.31; $\chi^2_{0.05}$ = 2.59; α = 0.05). The difference between sexual maturities of both sexes was not significant (p >0.05; α = 0.05; p-value = 0.31; t-value= 2.14; df. 14).

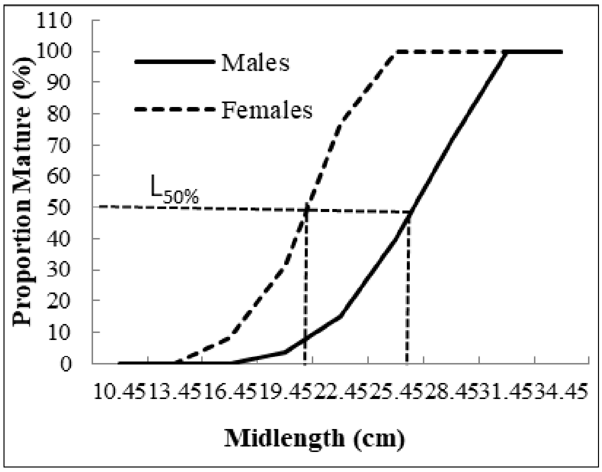

Fig 4: Length at first maturity ogive for *G. decadactylys* in Sierra Leone.

3.2. Length Growth

The infinity length (L_∞) and the index of growth rate (K) were estimated as 43.3 cm, 0.34 year^{-1} respectively, whereas the Z/K ratio gave 3.9. Figure 5 illustrates the Powell-Witherall plot for estimating L_∞ and Z/K ratio, a negative slope with strong negative correlation (r = -0.970) between the axis and expressed by the relation: Y = 8.86 + (-0.205)* X.
Moreover, the theoretical age (t_0) and lifespan (t_{max}) of the study species were estimated as -0.7 years and 8.1 years respectively. Therefore, the Special von Bertalanffy Growth model for length of *G. decadactylus* was predicted as:

$$L_t = 43.3\,(1 - e^{-0.43\,(t+0.7)})$$

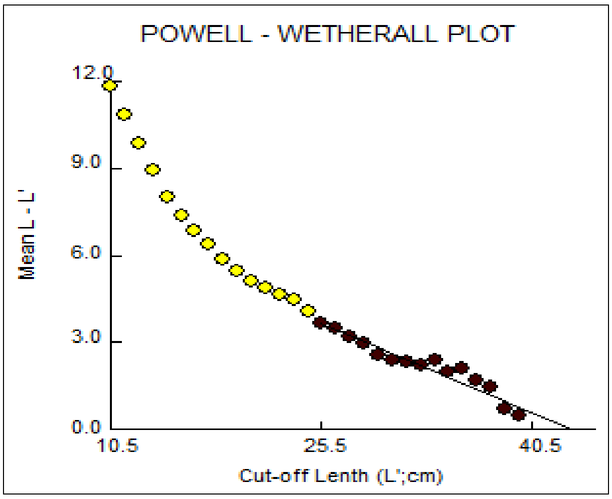

Fig 5: FiSAT II output of Powell-Witherall Plot for estimating $L\infty$ and Z/K ratio for *G. decadactylus*

Figure 6 shows a least square regression length-weight relationship for combined sex of *G. decadactylus* with regression coefficient/slope (b), best-fit determinant (R^2) and a regression correlation coefficient (r). The maximum total length (L_{max}) recorded for the species was 39.5 cm and weight (W_{max}) was 603g.

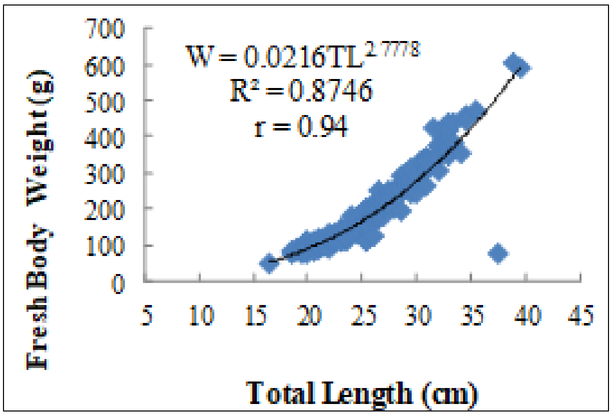

Fig 6: Least square regression length-weight relationship for *G. decadactylus*

3.3. Mortality and Current Exploitation Rates

Instantaneous Total (Z), Natural (M) and Fishing Mortality (F) rates were estimated as 1.58 $year^{-1}$, 0.77 $year^{-1}$ and 0.81 $year^{-1}$ respectively, whereas the current exploitation rate ($E_{current}$) was 0.51 $year^{-1}$. Similarly, the optimum fishing effort (F_{opt}) and the permissible fishing limit (F_{limit}) were calculated to be 0.31 $year^{-1}$ and 0.51 $year^{-1}$ respectively.

4. Discussions

4.1. Spawning Indicators

Results statistically portrayed numerical gender equality in the population of *G. decadactylus* owing to the insignificant deviation (p>0.05) of the observed sex ratio from the hypothetical ratio of 1:1 in spite of the colossal gap in the female: male sex ratio of 1:1.8. A similarly biased female: male sex ratio has been observed for the study species (F: M, 1:1.8; 1:1.27; 0.46:1) [20, 21, 22]. Major spawning in *G. decadactylus* may be occurring in October owing to high GSI relative to increased liver weight (HIS), and the species could be a partial spawner due to its protracted spawning behaviour (August through October). Major spawning has been reported to occur in July-December for *G. decadactylus* [1]. The occurrence of minor and major spawning in May/June and December has similarly been documented for the study species [22, 23]. The observed proportional relationship between GSI and HSI at major spawning from this study also purported that either of HSI and GSI could be used as indices of spawning in *G. decadactylus*. Further, the present study indicated long-overdue first sexual maturity in both sexes of the assessed stock (Female, $L_{50\%}$ = 50% $L_{max;}$ Male, $L_{50\%}$ = 35%L_{max}). A similar length at first sexual maturity observed for female specimens in the present study has been revealed for *G. decadactylus* ($L_{50\%}$ = 18.5 cm [24], but much lower value for both sexes has also been reported ($L_{50\%}$ <16 cm TL: [20, 25, 26].

4.2. Growth, Mortality and Exploitation *Rates.*

Length Growth in *G. decadactylus* may be obeying the special von Bertalanffy growth model ($L_\infty > L_{max}$;) [12] and its total length could be hardly exceeding 43.3 cm. Similar asymptotic length (L_∞ = 41.2 cm) had been noted for the study stock [27], whereas a much lower value (L_∞ = 26.25cm,) [21], and higher infinity length (L_∞ = 54.1 cm; L_∞ = 54.5 cm,) [28, 3] has been reported. The observed growth exponent from this study implied that length and weight of *G. decadactylus* may be growing at different rates (Negative allometry: b < 3.0,) [22, 29]. The estimated 'R^2' and 'r' value were, however, indicative of a perfect correlation between length and weight of the assessed stock [30]. However, the species may also grow isometrically (b =3.0,) [31].

Other growth parameters from this study also suggested a slow growth rate (K), earlier age at birth (t_0 <1 year) and death (t_{max}<12) for *G. decadactylus* in Sierra Leone, compared to other West Africa regions. A slower growth rate [3, 27, 28, 31, 32], similar theoretical age (t_0 = -0.75 and greater longevity t_{max} = 15.8 years [3], and much lower 't_0' [21, 31] have been observed in the assessed fish. Slightly higher theoretical age (t = -0.82) and higher longevity (t_{max} = 14.98) of the assessed species from the Ghanaian coast have also been noted [31].

Further, the mortality rates in the present study ($F_{current} > F_{opt}$) indicated colossal fishing pressure on the assessed stock, and the option to reduce the current fishing mortality rate by 62% through stringent fishery policies on the use of appropriate fishing gears and mesh sizes is advise in order to enhance fishing at optimal limit ($F_{current} = F_{opt}$). High fishing pressure on the stock of the study species off Liberian Coasts has been reported [3]. However, despite the observed increased fishing pressure, the current exploitation rate of the stock of *G. decadactylus* was within recommended optimal level ($E_{current}$ = 0.5 $year^1$: [19, 33, 34]), strengthened by the estimated Z/K ratio (Figure 5) within safe limit for survival of the spawning biomass (Z/K > 2: [6, 35]. Nonetheless, it would be much safer if the current exploitation rate were to be reduced by a minimum of 20% by reducing fishing efforts (number of licensed fishing vessels) over time.

5. Conclusion

Results statistically portrayed numerical gender equality in the population of *G. decadactylus* owing to the insignificant deviation (p>0.05) of the observed sex ratio from the hypothetical ratio of 1:1 in spite of the colossal gap in the female: male sex ratio of 1:1.8. The study species could be a partial spawner owing to its prolonged spawning period (August through October), and major spawning may be occurring in October relative to large increase in liver weight, also purporting that either of HSI and GSI could be used as indices of spawning in the assessed species. Besides, both sexes of *G. decadactylus* may be having overdue first sexual maturity.

Length Growth in *G. decadactylus* may be obeying the special von Bertalanffy growth model ($L_\infty > L_{max}$) and its total length may hardly exceed 43.3 cm. Other growth parameters of this study also suggested a slow growth rate (K = 0.34 yr^{-1}), earlier age at birth (t_0<1 year) and death (t_{max} <12 years) of *G. decadactylus* in Sierra Leone, while its length and weight may be growing disproportionately (b<3.0).

Further, the mortality rates ($F_{current} > F_{opt}$) were suggestive of a very high fishing pressure on the stock of *G. decadactylus,* and the option to reduce the current fishing mortality rate by 62% through stringent regulations on appropriate fishing gears and mesh size in order to obtain optimal fishing level ($F_{current} = F_{opt}$) at the least should be considered. However, despite high fishing pressure, current exploitation of the stock of *G. decadactylus* was at recommended optimal level (E = 0.5 $year^1$), strengthened by the estimated Z/K ratio (Z/K >2). Nonetheless, it would be much safer if the current exploitation rate were to be reduced by a minimum of 20% through reducing fishing efforts (number of licensed fishing vessels) over time.

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7. Declaration of Competing Interest

The author declares that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

8. Conflict of Interests

The author declares that there is no conflict of interest over the submitted manuscript.

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