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Growth, exploitation parameters and sexual maturity of *Chrysichthys nigrodigitatus* (Lacépède, 1803) downstream of the Taabo dam (Bandama River, Côte d'Ivoire)

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Abstract
The objective of the present work is to study the growth, exploitation parameters and the size of first sexual maturity of *Chrysichthys nigrodigitatus* (Lacépède, 1803) landed in N'dènou, in order to evaluate the status of its stock. A total of 7635 fish were sampled monthly from November 2019 to October 2020. The individuals were measured, weighed and the data processed with the FiSAT II software. The calculated parameters are: allometry coefficient (b = 2.77); asymptotic length ($L\infty$ = 51.98 cm); growth coefficient (K = 0.2 yr^{-1}); growth performance index (φ' = 2.73); natural mortality (M = 0.54 yr-1); fishing mortality (F= 0.61 yr^{-1}); total mortality (Z = 1.14 yr^{-1}); exploitation rate (E = 0.53). The size of first capture is smaller than the size of first sexual maturity. Recruitment is continuous with the peak during the rainy season. The *C. nigrodigitatus* stock is under fishing pressure in the Bandama River.

Keywords: *Chrysichthys nigrodigitatus,* exploitation rate, sexual maturity, growth, Bandama river

1. Introduction

Fishery products have an important role in the diet, poverty reduction and economy of human populations. In West Africa, fish and shrimp are the mainly exploited fisheries resources (Bédia *et al*., 2017) [1]. For the Ivorian consumer, especially for the country's most modest households, fish represents 70% of the animal protein consumed due to its relatively affordable price compared to meat (Aloko-N'Guessan and Kouman, 2010) [2]. The Ivorian territory has four major rivers, namely the Comoé, Bandama, Sassandra and Cavally. Human impact has increased significantly on the Bandama River, with the construction of two large dams for hydroelectric use (Kossou in 1971 and Taabo in 1978) and many other small dams for hydro-agricultural use in the upstream part of the river. According to Gourène *et al.* (1999) [3], development work such as the construction of dams, overexploitation due to intensive fishing and pollution of various origins in the aquatic environment have consequences for the sustainability of fishing.

In N'denou, in the southern part of the Bandama River, several landings of a multitude of fish species are made, including *Chrysichthys nigrodigitatus* of the Claroteidae family. This fish is abundant in the catches and is highly prized for its taste and commercial value. The problem that arises from the exploitation of fishery resources such as *C. nigrodigitatus* is how to ensure its sustainable exploitation? To answer this question, a rational management plan for the resource stock must be developed. However, this sustainable management cannot be done without controlling the biological parameters, especially those of reproduction, growth, exploitation parameters. The available data on the growth and exploitation parameters of *C. nigrodigitatus* are those from the work carried out by Bédia *et al*. (2017) [1] in the Ebrié lagoon, by Cissé *et al*. (2021) [4] in Lake Ayamé. The objective of this work is to determine the status of the *C. nigrodigitatus* stock in the Bandama River in the N'dènou area in order to consider a sustainable and balanced management of this fish stock.

2. Material and methods

2.1 Study area

The study area is located on the portion of the Bandama River downstream of the Taabo Dam and upstream of the construction area of the future Singrobo-Ahouaty Dam (Fig. 1). This environment is under the direct influence of the functioning of the Taabo dam. This site was chosen because of the commercial fishing activities that take place at the N'Dènou landing and the impact that the dam under construction could have on this area. It is easily accessible in all seasons.

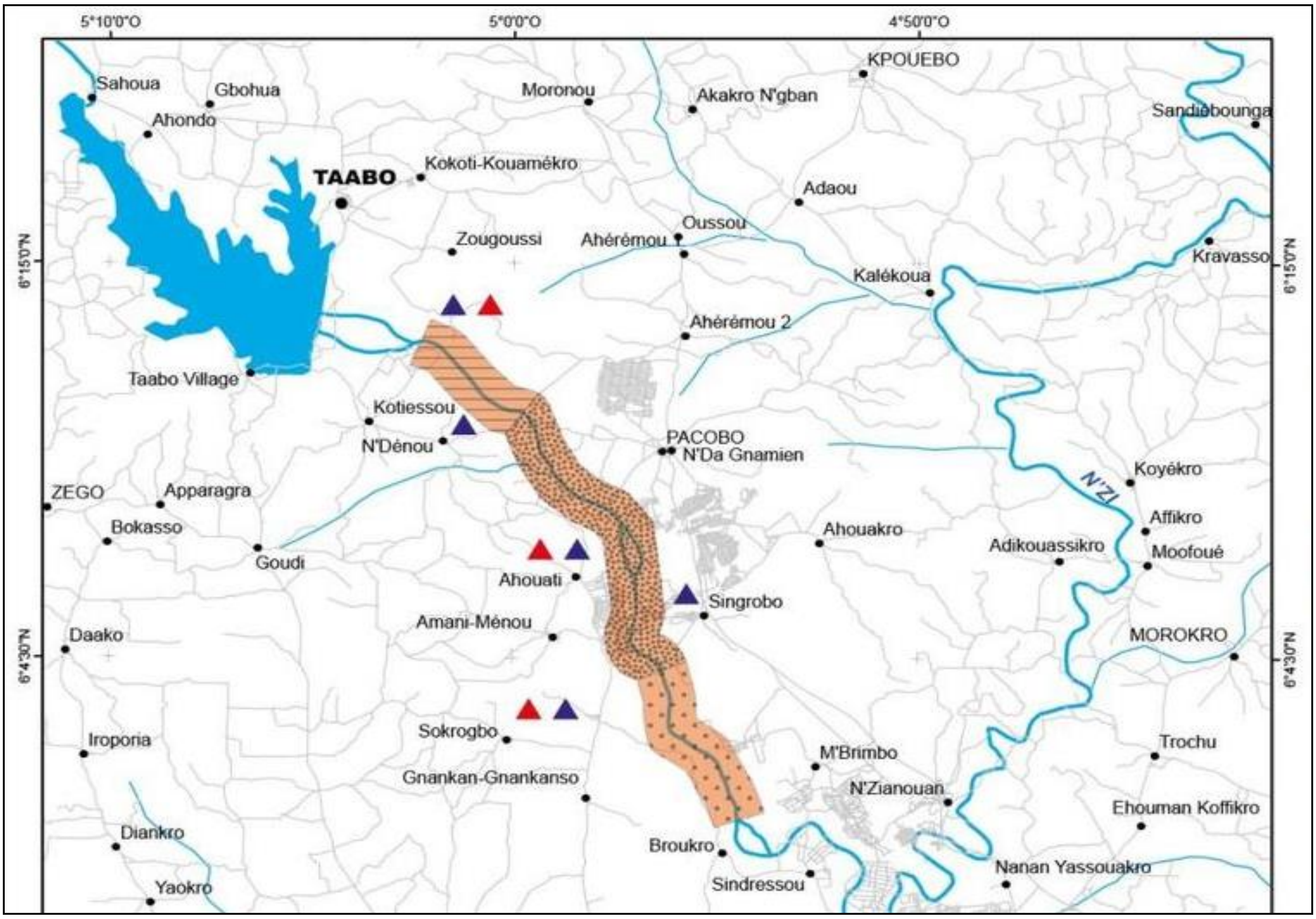

Fig 1: Geographic location of the study area (BNETD, 2017) [5]

2.2 Data collection

Data were collected monthly from November 2019 to October 2020. The fish examined were from the commercial fishery. Fish were caught using gill nets and creels. These gears are made with filaments of 20 to 70 mm mesh size. The captured fish were identified using the key of Paugy *et al*. (2003) [6]. Fish were then weighed to the nearest thousandth of a gram and standard lengths were measured individually to the nearest centimeter. For a better representation of the different size classes, the collected individuals were grouped in classes of 1 cm interval. A total of 205 individuals were dissected to determine sex and gonadal maturity stage according to a macroscopic scale inspired by the work of Laléyè *et al.* (1995) [7].

2.3 Data processing

2.3.1 Length-mass relationship

The length-mass relationship was established according to the following formula: $M = aSL^b$;

M = mass of fish in g; SL = standard length of fish in mm; a = intercept of the regression line and b = allometry coefficient. The parameters a and b were estimated after the transformation of the previous function into a logarithmic function of formula:

$$Log_{10} M = Log_{10} a + b \, Log_{10} SL$$

The value of b gives information about the type of growth of the fish. Student's t-test was used to test whether the obtained value of b differs significantly from 3. The null hypothesis of isometric growth (H_0: b = 3) was tested using the ts = (b-3)/SE statistic of Sokal and Rohlf (1987) [8] where ts is the calculated t-value of the test; SE, the standard deviation of the b-slope at p-value = 0.05. If ts > 1.96, this implies that b ≠ 3, so growth is allometric (allometry is negative if b < 3 and positive if b > 3) and if ts < 1.96 this implies that b = 3, so growth is isometric.

2.3.2 Estimation of growth parameters

The parameters of the Von Bertalanffy growth function including the asymptotic length (L∞), growth coefficient (K), and growth performance index (φ') were estimated using the ELEFAN I routine incorporated into the FiSAT II software. The model used was that of Von Bertalanffy (1938) [9] whose formula is as follows: $Lt = L\infty \, (1 - e^{-K\,(t - t_0)})$

Lt = The size of the fish at age t; L∞ = asymptotic length, this is the average size a fish would reach if it could live and grow indefinitely. K = growth coefficient, it characterizes how fast the fish grows towards the asymptotic length. t_0 = theoretical age for which the fish has zero length. Theoretical age (t0) was estimated using the empirical equation of Pauly (1979) [10]:

Log_{10} (-t0) = a + b Log_{10} + c L∞ Log_{10} K where: a = - 0.3922; b = - 0.2752 and c = -1.038

The growth performance index (φ') was calculated using the growth parameters (L∞ and K) according to the following equation: φ'= Log_{10} K + 2 Log_{10} L∞.

2.3.3 Mortality and exploitation rate assessment

Total mortality (Z) can be defined as the number of individuals that died during a given time interval. Its estimation is carried out by the method of "catch curves according to converted lengths" through the formula of Pauly *et al*. (1995) [11]: Ln (Ni/Δti) = a + b ti where Ni = number of individuals in size class i; Δti = time taken for the fish to grow into that class i; t = relative age at mid-length of size class i; b = the slope of the regression curve. The method used to estimate natural mortality is the empirical model of Pauly (1984) [12] using the following formula: Log_{10} M = w + x Log_{10} L∞ + y Log_{10} K + z log_{10} T.

Where: w = - 0.0066; x = - 0.279; y = 0.6543; z = 0.4634; M = natural mortality; L∞ = asymptotic length; K = growth coefficient; and T = mean annual water temperature.

Fishing mortality (F) and exploitation rate (E) were estimated according to Sparre and Venema (1992) [13] by the following relationships:

F = Z - M and E = F/Z or Z = F + M so E = F/(F + M)

The state of exploitation of a stock is optimal when E = 0.50. It is under-exploited when
E < 0.5 and over-exploited when E > 0.5 (Gulland, 1971) [14].

2.3.4 Size of first capture (L_C)

The length catch curves were used to determine the probability of capture of each size class according to the method of Pauly (1987) [15]. By plotting the cumulative capture probability against the average sizes, the selectivity curve is obtained which allows the graphical determination of the selectivity parameters (L_{25}, L_{50}, L_{75}). L_{50} or L_C is the size at which 50% of the fish are vulnerable to capture.

2.3.5 Determining the size of first sexual maturity

The size of first sexual maturity is the size at which 50% of individuals have reached sexual maturity (Oussou *et al*., 2019) [16]. The size of first sexual maturity was determined by considering fish with gonads at stages 3, 4 and 5 of sexual maturity as mature (Gorbel *et al*., 1996) [17]. The cumulative percentage of mature individuals per 1 cm interval, weighted by the total number of individuals for each size class is on the ordinate. The abscissa point, corresponding to the 50% projection on the curve, gives the size of first sexual maturity. The resulting sigmoidal shape function allows to follow the degree of sexual maturity by size and to estimate accurately the standard length (SL_{50}) from the following equation of Gorbel *et al*. (1996) [17]: $P = \frac{1}{1+e^{-(a+b\,LS)}}$ where P = proportion of mature individuals, SL = Standard length (cm); a and b, constants. From this equation, the sizes at SL_{50} can be deduced by calculating the following ratio:

$$SL_{50} = -\frac{a}{b}$$

2.3.6 Determination of the recruitment mode

Using the growth parameters, the ELEFAN I routine incorporated in the FiSAT II software was used to determine the recruitment mode of the stock. The back projection on the time axis of the available length frequency data allows to obtain the histograms showing the monthly variation of the recruitment intensity in percentage. The normal distribution was determined by NORMSEP (Pauly and Caddy, 1985) [18].

2.3.7 Yield per recruit (Y'/R) and Biomass per recruit (B'/R)

To estimate the exploitation levels of *C. nigrodigitatus* stocks, the ratio of yield per recruit (Y/R) and biomass per recruit (B'/R) as a function of exploitation rate (E) were determined. The models used were those of Beverton and Holt (1966) [19]:

$Y'/R = EU^{M/K}\,[1- (3U)/1 + m) + (3U^2/1 + 2m) - (U^3/1 + 3m)]$

Where

U = 1 – (Lc/L), m = (1 – E)/(M/K) = K/Z et E = F/Z = F/ (F + M).

The relative biomass yield per recruit was estimated by the relationship: B'/R = (Y'/R)/F

The curves of relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) were used to graphically determine the biological reference points E_{max} (Exploitation with the maximum productive yield), E_{10} (Exploitation rate for an increase in Y'/R of 1/10 of its value at E = 0) and E_{50} (Rate for which the stock is reduced to 50% of its unexploited biomass) according to the Knife-Edge method of the FiSAT II software (Bédia *et al*., 2017; Cissé *et al*., 2021) [1, 4].

3. Results and discussion

3.1 Length-mass relationship

The standard length of the individuals (n = 7635) varies between 7.2 and 37 cm for a mass between 6.32 and 630.65 g. The results are presented as a curve (Fig. 2). The regression equation obtained from this curve is as follows: $M = 2.80 \times 10^{-2} \times SL^{2.77}$ (r = 0.94).

The value of the allometry coefficient (b) is 2.77. This value is statistically different from 3 according to the Student's t test (ts = 12.07; $p<0.05$) performed. This indicates that the growth of *C. nigrodigitatus* is a negative allometry. The fish grows faster than it gets bigger (Lévêque, 2006) [20].

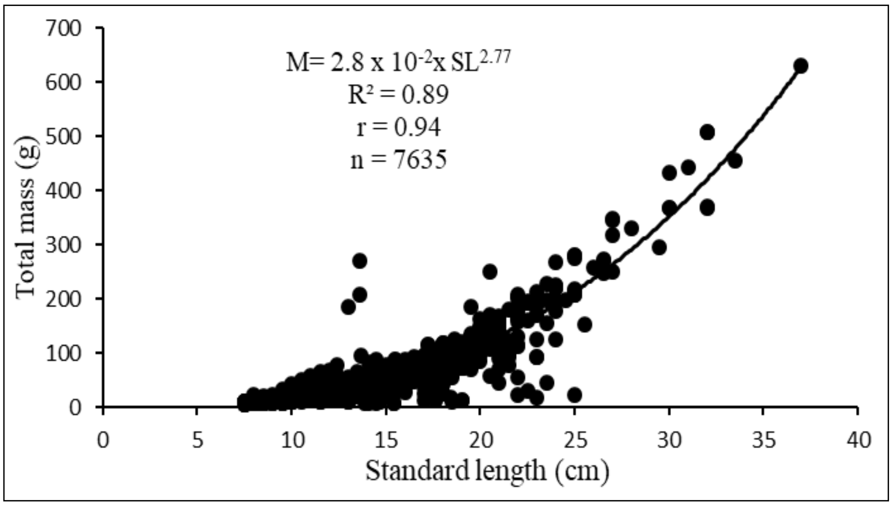

Fig 2: Relation standard length-total mass of individuals of *C. nigrodigitatus* captured in the Bandama River (r = correlation coefficient; SL = standard length, M = total mass and n = number)

3.2 Growth parameters

The estimated values of asymptotic length (L∞) and growth coefficient (K) are 51.98 cm and 0.2 yr-1, respectively. The resulting size frequency distribution yields the growth curves in figure 3. The growth performance index (φ') is 2.73 and the determined t0 value is -0.067 yr. The various parameters calculated allow us to define the Von Bertalanffy growth function as $L_t = 51.98[1 - e^{-0.2(t-t_0)}]$. The estimated parameters of the Von Bertalanffy growth function are summarized in the table. The asymptotic length (L∞) obtained is less than that reported by Cissé *et al*. (2021) [4] in Lake Ayamé for the same species (53.26 cm). The observed difference could be explained by the variability of the study environments, and by fishing pressure, among other factors (Okogwu *et al*., 2010) [21]. The growth coefficient (K) is less than 1 (0.20 yr^{-1}) which indicates that the growth rate is slow for this species. This observation corroborates that of Longhurst and Pauly (1987) [22] that freshwater fish reach their maximum size later due to slower growth.

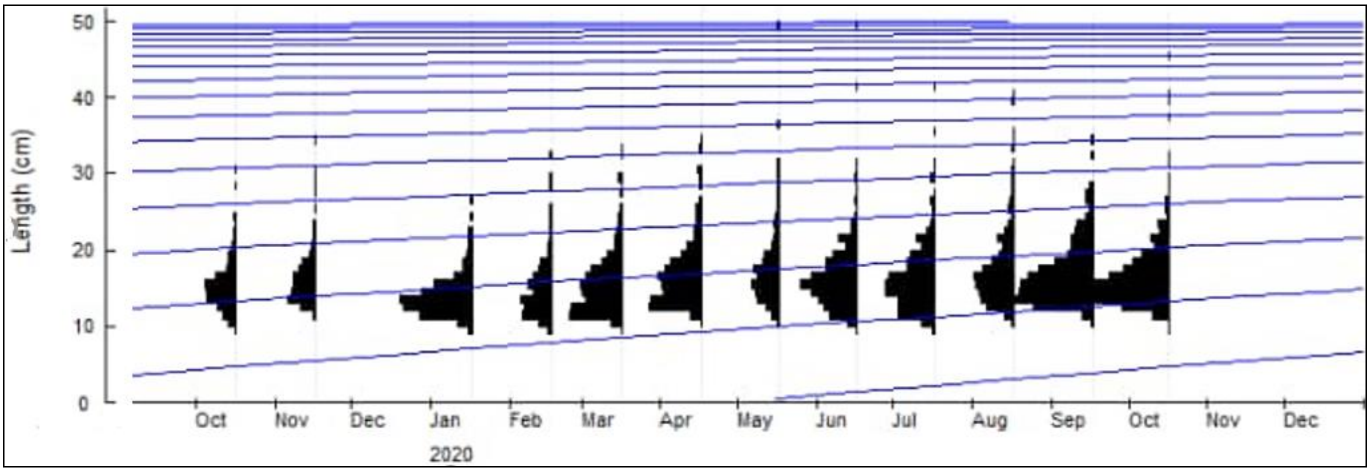

Fig. 3: Size frequency histograms and superimposed growth curves of *C. nigrodigitatus* according to the Von Bertalanffy model

Table 1: Growth parameters of *C. nigrodigitatus* from the Bandama River

Growth parameters	Values
Asymptotic length (L∞) in cm	51.98
Growth rate (K) in yr^{-1}	0.20
Performance index (φ')	2.73
Score (Rn)	0.24
Theoretical age (T_0) in years	-0.067

3.3 Mortalities, exploitation rate and yield per recruit (Y'/R)

The value of total mortality (Z) shown on the catch curve is 1.14 yr^{-1} (Fig. 4). The estimated natural mortality (M) is 0.54 yr^{-1} for a mean annual temperature of 28 °C. The fishing mortality (F) determined is 0.61 yr^{-1}. The exploitation rate (E) is 0.53. The maximum exploitation limit (E_{max}) estimated from the relative yield and relative biomass per recruit curves is 0.46 (Fig. 5). The marginal rate (E_{10}) is 0.37 and the exploitation rate (E_{50}) is equal to 0.27.

These results indicate that the species is a victim of non-selective fishing gears and that the *C. nigrodigitatus* stock is slightly overexploited. Indeed, according to Francis *et al*. (2007) [23] and Cissé *et al*. (2021) [4], the maximum level of exploitation of a resource is reached when the exploitation rate is higher than 0.5 or when fishing mortality (F) is equal to or higher than natural mortality (M). In the present study, fishing mortality is greater than natural mortality and the value of E (0.53) and greater than the optimal exploitation rate of yield (E = 0.5).

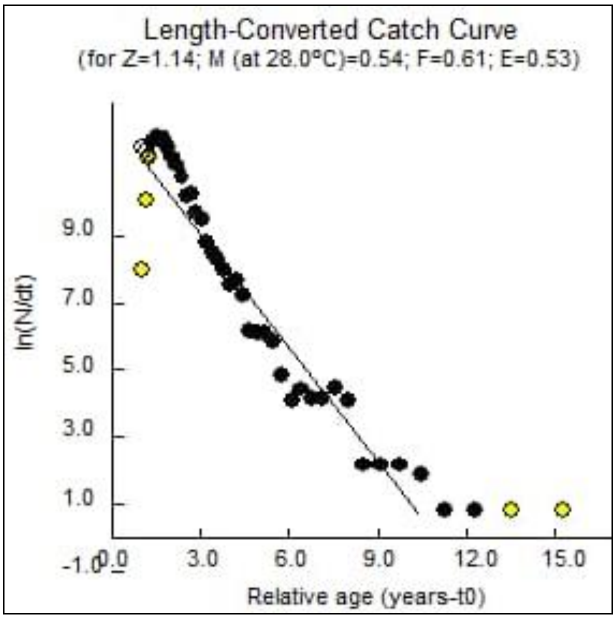

Fig 4: Capture curve by length of *C. nigrodigitatus*

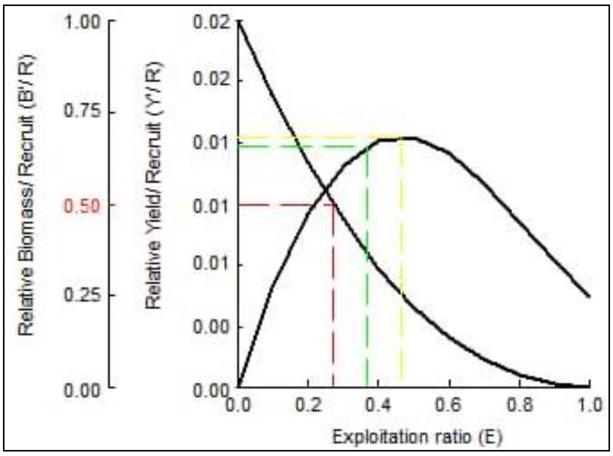

Fig 5: Curve of relative yield per recruit and relative biomass per recruit of *C. nigrodigitatus*

3.4 Size of first capture and size of first sexual maturity

The sizes at which 25 and 75% of the fish entering the traps are retained are 10.03 cm and 11.61 cm (Fig. 6). The size of first capture (Lc= L_{50}) which is the size at which 50% of the individuals are vulnerable to capture is 10.82 cm. It is smaller than the size of first sexual maturity (SL_{50}) which is 20.3 cm for males and 18.2 cm for females (Fig. 7). The size of first capture is a biological indicator and a vital parameter that indicates the health status of the resource and should be considered together with the size of first sexual maturity in the rational management of this fishery resource (Chikou *et al*., 2011) [24]. In our study, the Lc is lower than the SL_{50}. This situation could be a threat to the conservation of this fish.

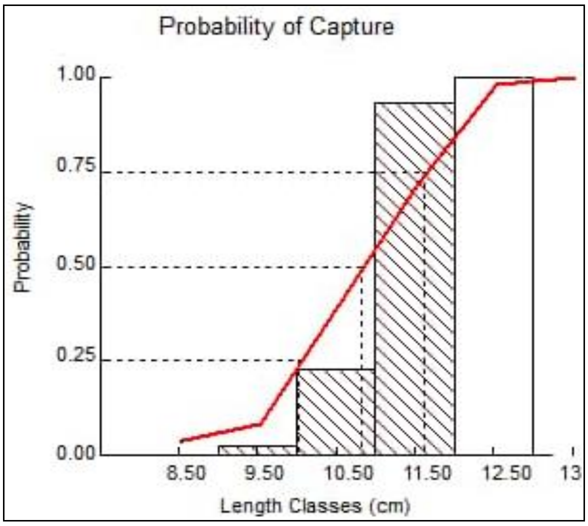

Fig 6: Selectivity curve showing the probability of capture for the size classes of *C. nigrodigitatus* in the Bandama River

3.5 Recruitment

The recruitment or process by which young *C. nigrodigitatus* enter the fishery is illustrated in figure 8 which shows a continuous recruitment throughout the year with a gradual increase from April to June when the first peak is reached. The second, less important peak is observed in September. These periods correspond to the main rainy season in the study area. Most tropical fishes reproduce during the rainy season when trophic conditions become favorable for juvenile growth. The recruitment period of *C. nigrodigitatus* appears to be similar to that of most tropical fishes mentioned by Pauly (1982) [25].

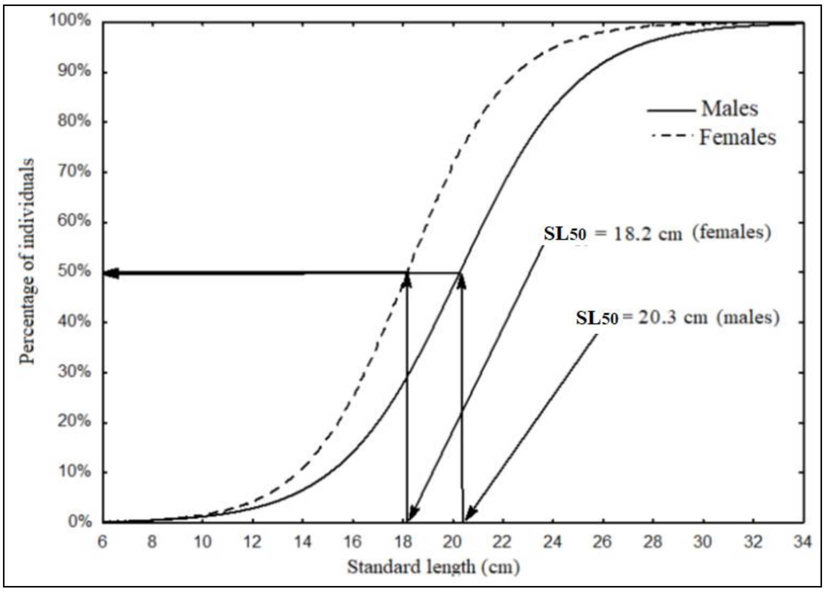

Fig 7: Determination curve of the size of first sexual maturity (SL_{50}) of C. *nigrodigitatus* captured in the Bandama River

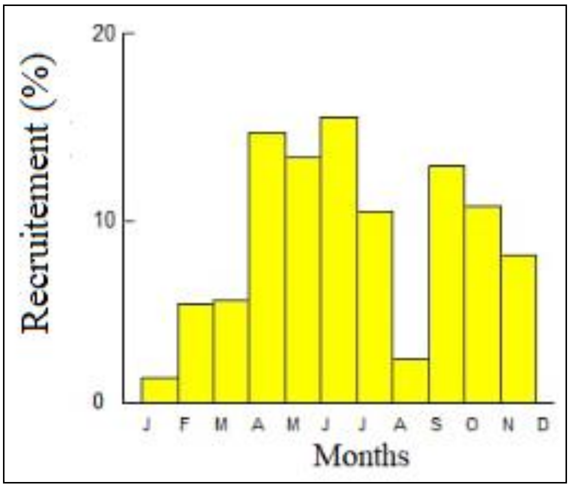

Fig 8: Recruitment curve of *C. nigrodigitatus* in the Bandama River

4. Conclusion

Downstream of the Taabo dam, on the Bandama River, individuals of *C. nigrodigitatus* grow faster than they get fatter. The appearance of young individuals in the fishing area is continuous throughout the year. The major peak in recruitment occurs in June which coincides with the rainy season. The results on the farm indicate that the stock of *C. nigrodigitatus* is under slight fishing pressure. Therefore, from a stock management point of view, the mesh size of the gears mainly used to catch this fish should be increased. This could allow smaller individuals to escape from the capture gears.

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