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Population parameters and exploitation levels of *Synodontis membranaceus*, a commercially valuable species in the Bagoué River in northern Ivory Coast

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ABSTRACT

The aim of this study is to determine the population parameters and exploitation level of *Synodontis membranaceus* in the Bagoué River in northern Côte d'Ivoire. A total of 690 specimens were collected every two months from August 2018 to February 2020. These specimens came from both commercial and experimental fishing. The sampled individuals ranged in size (LS) from 6.2 cm to 23.5 cm. Analysis of the size frequency distribution using FiSAT II software yielded growth parameters such as L∞, K, and to with respective values of 26.11 cm, 0.64 year-1, and -0.26 year-1. The natural mortality (1.38 year-¹) observed is higher than fishing mortality (1.34 year-¹). The exploitation rate (E = 0.49), which is below the optimal exploitation rate (E = 0.5), shows that the species is under-exploited. It would therefore be beneficial to maximize fishing activities for this species in order to reach its optimal rate. However, as natural mortality for this species is higher than fishing mortality, this should prompt researchers and decision-makers to conduct further research into the factors responsible for this natural mortality and take measures to prevent the decline of this species.

Key words: Growth, Mortality, Exploitation, Bagoué river, Ivory Coast

INTRODUCTION

The fishing industry in Ivory Coast provides 70000 direct jobs and 400000 indirect jobs (PND, 2015). Fishery products, specifically fish, account for more than 70% of animal protein (Micha and Franck, 2004), with consumption levels between 15 and 20 kg per capita per year (FAO, 2015). Fish demand has risen from 300000 to 350000 tons per year (PSDPA, 2014), while average local production is 80000 tons per year (FAO, 2014). To meet this ever-increasing demand, improving fishing techniques, expanding fishing areas, and increasing the number of fishermen and fishing gear on the water have been presented as the quickest alternative for increasing catches (FAO, 2004; Kantoussan, 2007). However, intensive fishing reduces the lifespan of fish and also leads to a reduction in the size at maturity of landed individuals, as well as a decrease in abundance and yields (Vanga *et al.*, 2002). According to Begg and Marteinsdottir (2003), high mortality due to intensified fishing can have adverse effects on fish reproduction parameters. Similarly, a decline in the number of large individuals in the stock has an impact on recruitment success, population dynamics, and stocking (Begg and Marteinsdottir, 2003). The risk of stock collapse is greater when fishing begins to target young fish that have not yet reached sexual maturity (Myers and Worm, 2005). This type of fishing limits the stock's renewal potential and has a negative impact on fishery productivity (Blaber *et al.*, 1999; Fromentin and Fonteneau, 2001). Given the danger posed by overfishing, monitoring fisheries and exploited species is necessary and essential for sustainable fishing and rational stock management. Such monitoring can only be effective if fisheries have reliable statistics and scientific data. In Côte d'Ivoire, data on artisanal fisheries do exist. This is the case for the dam lakes of Ayamé 1 (Cissé *et al.*, 2025), Buyo (Goli Bi *et al.*, 2019), Kossou (Da Costa and Konan, 2005), Taabo (Konan *et al.*, 2019), the Aghien-Potou lagoon (Bedia *et al.*, 2009), and the Bandama River (Boghué *et al.*, 2011; Kien *et al.*, 2015). Unfortunately, such data is virtually non-existent for the Bagoué River and the species exploited there. However, due to its location, the Bagoué River is of paramount importance to this region of Côte d'Ivoire. It is the main source of water and the only one during the dry seasons. The riverside populations derive most of their livelihood from it, particularly for agro-pastoral activities and consumption (N'da, 2015). In addition, the Bagoué River has a very important ichthyological biodiversity, which is an undeniable asset for the riverside populations (Sanogo *et al.*, 2015). It represents a fishing potential that is exploited throughout the year by the riverside populations, and the catfish *Synodontis membranaceus* is considerably represented in the catches. Synodontis membranaceus, a catfish found in this river, is highly prized by consumers and also has a high market value. It is caught on a massive scale by artisanal fishermen in an unregulated manner.

This has led to an intensification of fishing and, as a result, an increase in catches. In order to prevent the depletion of its stock, the management of *S. membranaceus* is essential. This involves studying the population parameters of this species. Knowledge of population parameters, particularly growth rates, allows for an estimation of the impact of fishing and helps in the implementation of a rational resource management policy (Chikou *et al.*, 2007). The objective of this study is to determine the current level of exploitation of *S. membranaceus* in the Bagoué River with a view to the rational and sustainable management of available stocks.

MATERIALS AND METHODS

Study area

The Bagoué River, located in northwestern Ivory Coast, lies between longitudes 6°10' and 6°60' west and latitudes 9°10' and 10°20' north (Adja *et al.*, 2009a) (Fig. 1). It is a transboundary river between Côte d'Ivoire and Mali (N'da, 2015) and, together with the Baoulé River, forms the two main secondary tributaries of the Niger River on Ivorian territory (Girard *et al.*, 1971). This river flows for a distance of 530 km, including 230 km in Ivorian territory (Sanogo *et al.*, 2015).

Its surface area is approximately 13,682 km² (Adja, 2009; Adja *et al.*, 2009b; N'da *et al.*, 2015) and its watershed covers the departments of Boundiali and Tengrela. This watercourse is entirely located in the savanna district, which has numerous dam lakes used for agro-pastoral purposes (Adja, 2009). The rainy season lasts from May to mid-November (Savané and Konaré, 2010).

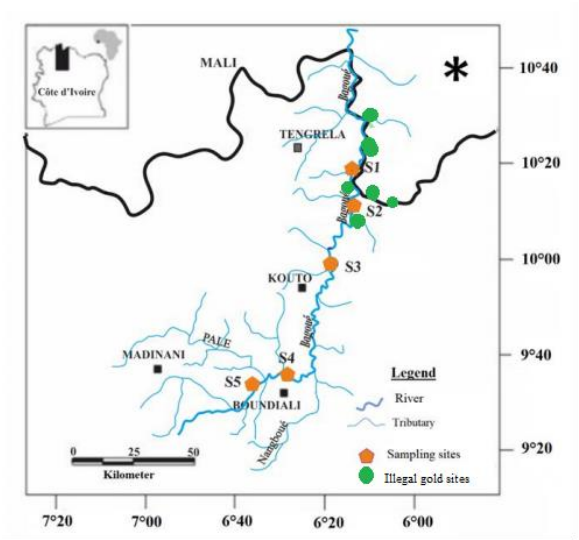

Fig. 1. Overview of the Bagoué River basin in Ivory Coast and location of sampling sites

Five sites (Fig. 1) were selected on the river, taking into account their accessibility, environmental characteristics, and, above all, the availability of fishermen and fishing activity (Kouyate *et al.* 2020).

Data collection

The fish examined in this study consist of specimens of *Synodontis membranaceus* (Geoffroy Saint-Hilaire, 1809) collected from the Bagoué River between August 2018 and February 2020.

These fish come from both commercial and experimental fishing. For experimental fishing, a series of gillnets (10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60) was used to capture a wide range of specimen sizes. The nets were set at 5 p.m. and lifted the next day at 7 a.m., then set again and removed at noon. For commercial fishing, the fish were collected from artisanal fishermen who had fished in the study area. Specimens were identified using the identification keys provided by Paugy *et al.* (2003). The length of each specimen was measured using an ichthyometer.

Growth parameters

Growth parameters were determined using FiSAT II software (version 1.2.2). Asymptotic length was determined using Pauly's method (1980). The theoretical age (t0) was determined according to Pauly (1979) using the following empirical equation:

Log10 (-to) = -0,392 – 0,275 Log10 L∞ - 1,038 Log10K

Recording size frequencies made it possible to estimate the individual growth of each specimen according to Von Bertalanffy's mathematical growth model (1938), which considers body length as a function of age t using the following equation:

$Lt = L\infty [1- e - k (t-to)]$

Lt: standard length of the fish at time t (cm), L∞: theoretical maximum length or asymptotic length, K: growth coefficient (year-1) and to: theoretical age of the fish when its size is zero.

The reliability of these parameters was tested by applying the growth performance index (φ') calculated according to the method of Pauly and Munro (1984):

$\varphi' = \log10\ K + 2\ \log10\ L\infty$

$t - to = tmax. = 2.9957 / K$

The absolute growth rate was determined using the following equation:

AGR = K (L∞ - Lt) (Pauly, 1984; Sparre and Venema, 1992)

Exploitation parameter

Total mortality (Z), natural mortality (M), fishing mortality (F), and exploitation rate (E)

Total mortality (Z) was estimated using the "length-converted catch curve method" through the following formula (Pauly, 1984):

$Ln (Ni/\Delta ti) = a + b\ ti$

Ni: number of individuals in size class i, Δti: time taken by fish to grow to size class i, t: relative age calculated with to = 0 corresponding to the mid-length of size class i, a: ordinate at the origin of the mortality curve and b: slope representing total mortality with a change of sign.

Natural mortality (M) is calculated in order to verify the consistency of the K and L∞ parameters. The method used is Pauly's empirical model (1984), which incorporates the temperature of the environment and the growth parameters K and L∞ into its expression according to the following formula:

Log10 M = - 0.0066 – 0.279 Log10 L∞ + 0.6543 Log10 K + 0.4634 Log10 T

M: natural mortality and T: average annual water temperature.

In this study, the temperature determined in the Bagoué River is 26°C.

Based on total mortality (Z) and natural mortality (M), fishing mortality (F) and the exploitation rate or level (E) were estimated using the following relationships:

F = Z – M and E = F / Z or Z = F + M, therefore E = F / (F + M)

According to Gulland (1971), the state of exploitation of a stock can be assessed based on the fact that optimum yield is achieved when F = M, i.e., when E = 0.50. The exploitation rate indicates that a stock is under-exploited when E < 0.5 and over-exploited when E > 0.5.

First capture size, optimal capture size, and recruitment period

The first capture size (L50 = Lc) is obtained from the capture curve converted to length using FiSAT II software (Pauly, 1983). This method allows L25, L50, and L75 to be determined. The L50 size corresponds to the first capture size. This is the size at which 50% of fish are likely to be caught. L25 and L75 correspond to the different sizes at which 25% and 75% of fish are caught, respectively (Pauly, 1983).

The optimal catch size is the size at which recruits should be caught to provide the maximum weight yield. It is expressed using Beverton's formula (1992):

$$L_{opt}=L_{\infty}\frac{3}{3+M/K}$$

L∞ is the asymptotic length (cm), M is the natural mortality, and K is the growth coefficient (year-1) of the Von Bertalanffy curve.

Recruitment was determined by projecting size frequency data onto the time axis using growth parameters (Moreau and Cuende, 1991). Normal distribution was determined by NORMSEP (Pauly and Caddy, 1985) with FiSAT II.

Yields and biomass per recruit

The Beverton and Holt (1966) model from the Fisat II Program was used to predict relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R). This model uses lengths. It is defined as follows:

Y'/R = EUM/k [1 – (3U/1 + m) + (3U2/1 + 2m) – (U3/1 + 3m)]

m = (1–E) /(M/K) = K/Z U = 1- (LC /L∞)

The relative biomass yield per recruit was estimated using the following relationship: B'/R = (Y'/R) /F This model can be used to estimate the following predictive values or reference points: E0.1, E0.5, and Emax. The FiSAT II version 1.1.0 software enabled the application of the Beverton and Holt model (1966) model.

RESULTS

Growth parameters

The size of the *Synodontis membranaceus* individuals sampled (n = 690) ranged from 6.2 cm to 23.5 cm in standard length. The asymptotic length (L∞) was 26.11 cm with an annual growth rate K of 0.64 year-1. The calculated growth performance index (φ') is 2.63 and the to value corresponding to the theoretical age is -0.26 cm. The goodness-of-fit value of the growth curves (Rn) or score is 0.30. The growth curve used for the determination is illustrated in Fig. 2.

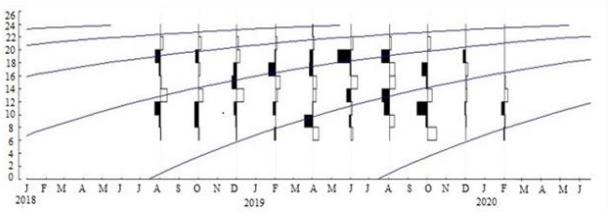

Fig. 2. Size frequency histogram and overlapping growth curves of *Synodontis membranaceus* captured in the Bagoué River from August 2018 to February 2020 (J: January; F: February; M: March; A: April; M: May; J: June; J: July; A: August; S: September; O: October; N: November; D: December).

The population parameters included in the Von Bertalanffy growth model give the following equation:

Lt = 26.11 [1- e – 0.64 (t+0.26)]

Lt: average size at age t; t: age of the fish at time t.

The linear growth shown in Fig. 3 is progressive up to 3 years of age. Beyond this age, it becomes very weak.

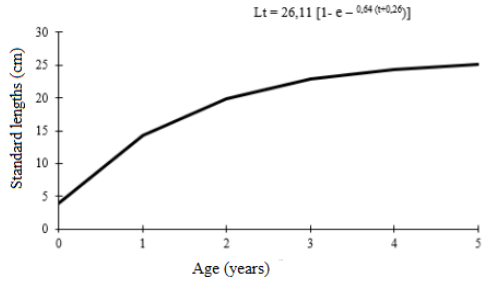

Fig. 3. Linear growth curve of *Synodontis membranaceus* according to Von Bertalanffy's equation in the Bagoué River from August 2018 to February 2020

Length by age class and absolute growth rate

The integration of growth parameters into the Von Bertalanffy equation made it possible to determine the standard lengths of age classes, the absolute growth rate, and the percentage of the asymptotic length of Synodontis membranaceus in the Bagoué River (Table 1). For age classes under one year, the growth rate of *S. membranaceus* is 14.24 cm/year. It decreases rapidly to 7.51 cm/year for those aged one year and to 3.96 cm/year in the second year. Beyond this age, a gradual decrease in growth is observed, reaching a value of more than 0.58 cm/cm in the fifth year.

Table 1. Standard length, absolute growth rate (AGR), weight, and percentage of asymptotic length (L∞) of age classes of *Synodontis membranaceus* caught in the Bagoué River from August 2018 to February 2020.

Age class	Standard length (cm)	CGA (cm/year)	Weight (g)	Percentage of L∞ (%)
<1	3.86	14.24	1.77	14.78
1	14.37	7.51	66.87	55.03
2	19.92	3.96	164.53	76.29
3	22.84	2.09	240.11	87.47
4	24.39	1.10	287.53	93.41
5	25.20	0.58	314.77	96.51

Exploitation parameters

Mortality coefficients and exploitation level

The total mortality value (Z) is 2.72 year-1 across the entire Bagoué region. Natural mortality (M) and mortality due to fishing are 1.38 year-1 and 1.34 year-1, respectively (Fig. 4). The exploitation rate (E) across the entire Bagoué region is 0.37 (Fig. 5). The maximum exploitation limit (Emax) assessed from the relative yield and relative biomass curves per recruit using the FiSAT II Knife-Edge method is 1.

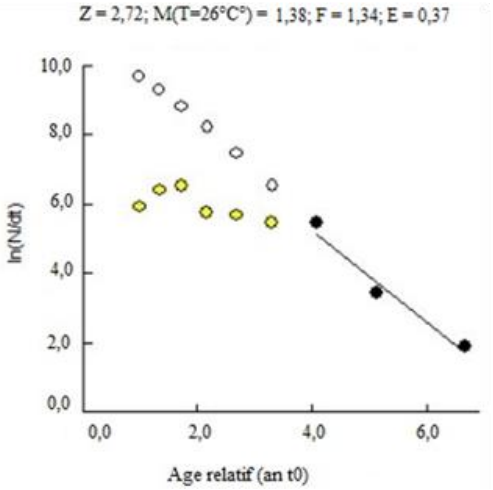

Fig. 4. Catch curve for *Synodontis membranaceus* in the Bagoué River from August 2018 to February 2020. (Z = total mortality; M = natural mortality; F = fishing mortality; E = exploitation rate; black dots: points used for the least squares calculation of the linear regression; yellow dots: points not taken into account for the calculation because they are too far from the asymptotic length; white dots: theoretical values that should be taken into account).

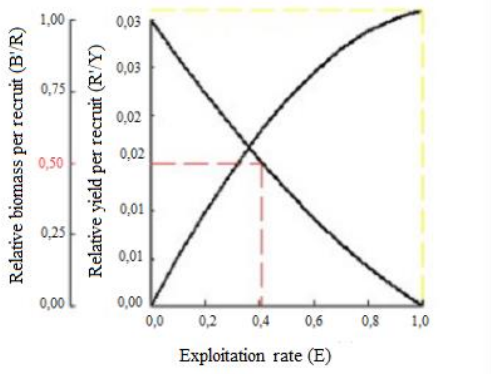

Fig. 5. Exploitation rate of *Synodontis membranaceus* in the Bagoué River from August 2018 to February 2020. (Yellow line = Emax; Red line = E50).

First capture size, optimal capture size, and recruitment period

The sizes corresponding to the 25%, 50%, and 75% capture probabilities of *S. membranaceus* in the Bagoué River

obtained from the selection curve are shown in Fig. 6. The first capture size (L50) in the Bagoué is 16.95 cm standard length. The sizes at which 25% and 75% of individuals are likely to be captured are 15.31 cm and 18.75 cm, respectively. The optimal capture size observed in the Bagoué River is 15.38 cm. The recruitment of *Synodontis membranaceus* juveniles in the Bagoué River is continuous throughout the year, but with varying percentages depending on the month. An increase in recruitment is observed from July to October, with the only peak (19.36%) occurring between September and October (Fig. 7).

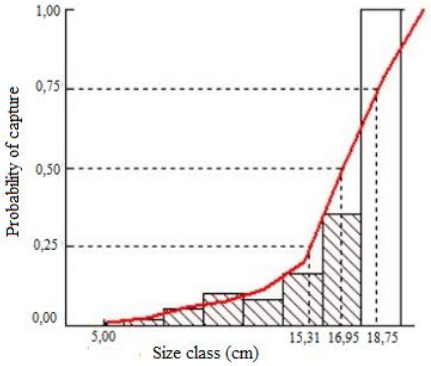

Fig. 6. Probabilities of capturing *Synodontis membranaceus* in the Bagoué River from August 2018 to February 2020 (The red line represents the evolution of capture probabilities according to size).

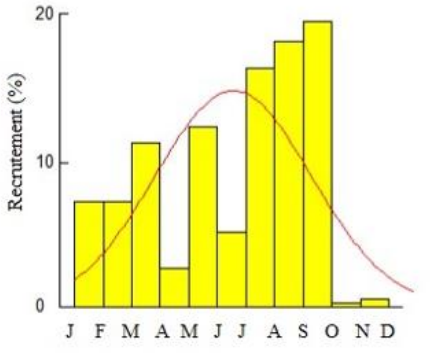

Fig. 7. Histogram of annual recruitment of *Synodontis membranaceus* caught in the Bagoué River from August 2018 to February 2020 (J: January; F: February; M: March; A: April; M: May; J: June; J: July; A: August; S: September; O: October; N: November; D: December). The red lines define the recruitment curves and the yellow histograms define the monthly recruitment levels.

DISCUSSION

The growth parameters L∞, K, and to obtained in this study differ from those obtained in previous studies. Indeed, the asymptotic length (L∞) is lower than that obtained by Abowei (2009) in the Niger Delta (41.2 cm) in Nigeria and by Akombo *et al.* (2016) in the Benue River in Makurdi (35 cm) in Nigeria for *S. membranaceus*. This difference indicates that the exploited stock of *S. membranaceus* in the Bagoué River in Côte d'Ivoire consists mainly of small individuals, with the exception of a few large specimens. The asymptotic length (L∞) obtained in the Bagoué is greater than the maximum standard length. This means that the species could grow further if the existing conditions in the river are favorable (Akombo *et al.*, 2016). The growth coefficient (K) value obtained in this study (0.64 year-1) is higher than the values obtained by Abowei (2009) and Akombo *et al.* (2016), which are 0.38 year-1 and 0.31 year-1, respectively, for the same species.The high value of this parameter can be explained by the fact that the population of *S. membranaceus* consists of more juveniles than adults, as reported by Wagué and Papaconstantinou (1997) in their study of the fish Serranus hepatus in the Thermaikos Gulf in Greece. The negative values of the hypothetical age (to) mean that *S. membranaceus* juveniles grow faster than the growth curve for adults (King and Etim, 2004). The growth performance index (φ') in this study is identical to the value found by Abowei (2009) for the same species. This value does not fall within the range of 2.65 to 3.32 defined by Baijot and Moreau (1997).

For these authors, such growth performance index values are attributed to tropical fish stocks known to grow slowly. The specimens of *S. membranaceus* examined in the Bagoué River can therefore be considered as slow-growing stocks. This low growth rate could be explained by changes in the physicochemical characteristics of the environment, as already demonstrated by Ofori *et al.* (2002). In addition, fish growth performance may depend on the specific potential of each species, which determines the responses observed during the larval and juvenile stages, or on the age at which maturation begins (Roff, 2000). The variation in growth parameters from one

environment to another is thought to be due to the specific ecological characteristics of the environments where the fish live, variability in food availability, fishing pressure, and sampling (Seyedahmadreza *et al.,* 2011). The longevity values obtained range from 4 to 5 years. These results are corroborated by the work of Abowei and Hart (2009). These authors estimated a longevity of 5 years for *Hemisynodontis membranaceus* in the Niger Delta. Midhat *et al.* (2012) also obtained a longevity of 6 years for Synodontis schall in the Nile in Egypt. The mortality parameter values obtained for *Synodontis membranaceus* show that natural mortality (M) is higher than fishing mortality (F) throughout the Bagoué and at the various stations. Natural mortality higher than fishing mortality has been reported for various species (Abowei and Hart, 2009; Abowei, 2009; Midhat *et al.* (2012). High natural mortality is due to environmental conditions, physiological factors (disease and old age), and random factors (encounters with potential predators and predation of eggs). In the Bagoué River, the most plausible hypothesis to explain the high rate of natural mortality is environmental conditions. Indeed, illegal gold mining in the river basin seriously degrades the aquatic environment by releasing heavy metals into the water (Kouamé *et al.*, 2020), increasing turbidity, and even destroying fish habitats (Laperche *et al.*, 2007). Furthermore, the calculated total mortality values Z are greater than 2. This total mortality is thought to be linked to natural mortality, which is itself a consequence of pollution caused by artisanal gold mining. These results are corroborated by the work of Bédia (2015). This author obtained a total mortality rate of 4.95 year-1 for Ethmalosa fimbriata in the Aghien lagoon. The exploitation rate (E) of *Synodontis membranaceus* in the Bagoué River and at each of the stations visited is below the exploitation limit rate (E = 0.5). Overfishing of a stock is observed when the exploitation rate reaches the hypothetical value of 0.5 (Sparre and Venema, 1992). *Synodontis membranaceus* is underfished in the Bagoué River. This low level of exploitation is thought to be linked to the proliferation of illegal gold mining sites along rivers, which reduces fishing areas and fishermen's access to fish. A wave of annual cohort recruitment was observed in this study. The recruitment of young *S. membranaceus* takes place from May to August, corresponding to the rainy season. The peak recruitment period (when juvenile specimens predominate during the year) is observed in October, May, June, and August. This phenomenon occurs during the rainy season, when trophic conditions become favorable for the growth of young individuals, as indicated in the work of Koné (2000). The results observed in this study are similar to those of Tah *et al.* (2009) and those of several authors who have studied the reproduction of tropical fish in Africa (Koné, 2000; Ouattara *et al.*, 2008).

CONCLUSION

At the end of this study, it should be noted that *Synodontis membranaceus* in the Bagoué River is under-exploited. The species has continuous growth with a high recruitment rate during the rainy season, which is favorable for juveniles. Analysis of *Synodontis membranaceus* population parameters indicates that natural mortality is higher than fishing mortality in the Bagoué River. This situation is thought to be linked to human activities such as illegal gold mining and agriculture using pesticides. Hence the need to call on decision-makers to take measures to ensure the sustainability of fishery resources in this water body.

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