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Population Dynamics of *Chrisychthys nigrodigitatus* ((Lacepede, 1803) and *Synodontis schall* (Bloch & Schneider, 1801) from Solomougou's Dam Lake (Côte d'Ivoire)

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Abstract: *In our studies on fishing activity in the Solomougou Dam Lake, Chrisychthys nigrodigitatus and Synodontis schall have been identified as the two most abundant siluriforms in catches. This study has been undertaken to assess the exploitation level of their stocks. Fish were collected monthly from January 2019 to December 2019. Results showed that current exploitation rates (E) are lower than reference point 0.5. for the both species. Also, exploitation levels maximizing relative yield per recruit (Emax), reducing stock to half its virgin biomass (E0.5) and at which the marginal increase in the relative yield per recruit is 10% of its value (E0.1) are higher than current exploitation rates. So, additional exploitation of specie's biomass is possible without forgetting that lengths at first capture are lower than sexual maturity lengths. Predictive studies showed that fishing mortality reducing stock to half its virgin biomass is 1.8 and 2.5 times greater than current fishing mortality registered for Chrysichthys nigrodigitatus and Synodontis schall, respectively. The application of those fishing efforts would lead to increase catches and economic values around by 34.33% and 23.55%, respectively for Chrysichthys nigrodigitatus, while for Synodontis schall, catches would increase around by 57.86% and by 37.81% for economic values.*

Keywords: *Morphological variations, populations, Chrysichthys nigrodigitatus, EbriéLagoon*

1. Introduction

Over 90% of global inland capture fisheries production is used for human consumption, the majority of which is in the developing world. In these countries, inland fisheries contribute significantly to food and economic security by providing sources of animal proteins and income [1]. Taking into account the number of fishermen (36% of all capture fishers worldwide) and other persons employed in post-harvest activities (over 36 million), inland fisheries have a proportionally higher influence on livelihoods than marine ones, particularly in Asia and Africa ([2], [3]). Despite their demonstrably large contribution, they generally receive little consideration in water resource allocation decisions [4].The lack of awareness is because information about these fisheries is inherently difficult to acquire because they are diverse, often small-scale and highly dispersed [5].Additionally, 65% of inland habitat is classified as moderately or highly threatened by anthropogenic stressors, so biological organisms may be extirpated even before they are documented [6].

In Côte d'Ivoire, the river system in the north of the country is mainly based on Dam Lakes, estimated today at 210 [7]. Originally built for crop irrigation and livestock rearing, they are now exploited for fishing purpose [8]. So they represent important sources of proteins in this region of the country. To this end, they deserve monitoring for their better management. In a prospective study that we conducted on one of them, that of the Solomougou Dam Lake, we identified almost a dozen species belonging to the group of siluriforms. In West Africa, 8 families comprising 24 genera and 124 species from this group have been reported [9]. This group of fish, commonly known as catfish, is also of great economic importance [10]. Two main species are remarkably abundant in catches. These are *Chrisychthys nigrodigitatus* and *Synodontis schall*. Moreover, unlike gillnets that are much more commonly used for cichlidaefishing, these two species are most targeted by specific fishing gear, including longlines and traps.

So the present work has the objective to assess the exploitation level of their stocks. Results obtained will ensure sustainable management of these commercial important species in this fishery.

2. MATERIALS AND METHODS

2.1. Study Area

This study has been undertaken in the biggest fishery in the department of Korhogo called Solomougou Dam Lake. Located in the North of Côte d'Ivoire (Figure 1), its watershed extends between the meridians 5°30' and 6° W and the parallels 9° and 9°30' N [11]. It covers a maximum area of 500 hectares of water [12]. The climate of the study area, like that of northern Côte d'Ivoire, is marked by two main seasons. The dry season covers the period from November to April and the rainy season from May to October. Average annual rainfall remains below 1200 mm and average annual temperature is 26.5 ° C [13].

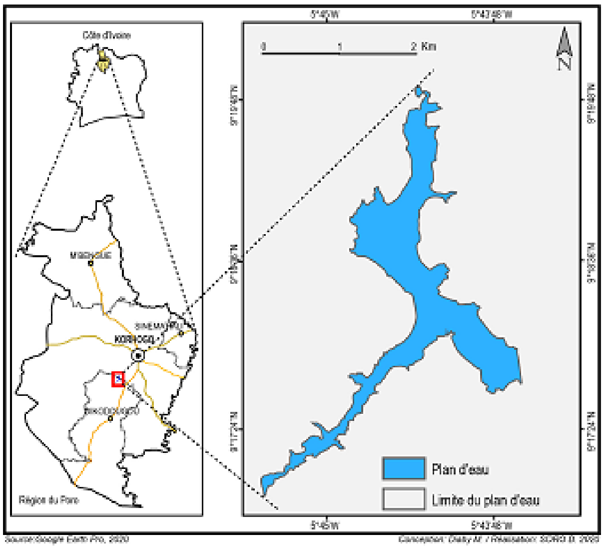


Figure1. *Location and morphology aspect of the Solomougou Dam Lake*

2.2. Data Collection

Samples of the two species were collected monthly from January 2019 to December 2019 from fishermen's catches. Fishing has been done mainly with different fishing gear including traps, longlines and bamboo traps. A total of 525 specimens of *Chrisychthys nigrodigitatus* and 1655 specimens of *Synodontis schall* were studied. Fish were identified to species level using identification keys [14]. For each specimen, total length was measured to the nearest 0.1 cm

2.3. Data Processing

2.3.1. Growth Parameters Estimation

Von Bertalanffy model has been used for modeling fish growth through the relation $L_t = L_\infty (1- e^{-k(t-t_0)})$, where Lt is the length at age t, L_∞ the asymptotic length, K the growth rate, and t_0 the theoretical age at which the fish length is zero [15]. The asymptotic length L_∞ and growth coefficient K have been calculated using ELEFAN programme of FISAT II software, while the theoretical age t_0 was estimated using the equation $\log_{10}(-t_0) = -0.3922 - 0.2752 \log_{10} L_\infty - 1.038 \log_{10} K$ [16]. Growth performance index (ϕ') was calculated using the equation $\phi' = \log_{10} K + 2 \log_{10} L_\infty$ [17] and longevity (t_{max}) from the relation $t_{max} = 3/K$ [18].

2.3.2. Mortality Parameters Estimation

The total mortality (Z) was obtained from the linearized length-converted catch curve method using the relation: $\ln(N_i/\Delta t_i) = a + bt_i$, where Ni is the number of specimens in the length class i, Δti is the time needed for the fish to grow through length class i, ti is the age corresponding to the mid length of class i, and b is the slope that estimates total mortality Z after change of sign [18].The natural mortality rate (M) was estimated using the empirical equation:

$Log_{10}M = 0.0066 - 0.279Log_{10}L_\infty + 0.6543Log_{10}K + 0.4634Log_{10}T$, where M is natural mortality, L_∞ and K are parameters of Von Bertalanffy equation and T is the annual average temperature of the environment, estimated at 27.2 ºC in this study according to monthly recordings [19]. The annual instantaneous fishing mortality (F) was obtained from the relation F= Z-M.

2.3.3. Exploitation Rate Estimation

The exploitation rate (E) is calculated with the equation E=F/Z. The overfishing state is observed when E>0.5, the underfishing state when E<0.5 and an optimal exploitation of the stock when E=0.5 [20].

2.3.4. Probability of Capture

The ascending part of the length converted catch curve is used to generate probabilities of capture. The extrapolated points were used to approximate the probability of capture by backward projection of the number that would be expected if no selectivity had taken place [21]. The probability of capture is calculated by the ratio of the numbers actually caught with those that "ought" to have been caught for each length group class. The lengths at capture at probabilities 25%, 50% and 75% correspond respectively to the length at which 25% (L_{25}), 50% (L_{50}, the length at first capture) and 75% (L_{75}) of the fish entering the gear are retained [22].

2.3.5. Virtual Population Analysis (VPA)

The Virtual Population Analysis, also called cohort analysis because each cohort is analysed independently, is a method that allows the reconstruction of the population from the total catch data by age or size. This method uses L_∞ and K as input parameters to provide information on natural mortality, fishing mortality and survivors in each length group. Here, it is assumed that all length classes caught during one year reflect that of a single cohort during its entire life span [22].

2.3.6. Relative Yield and Biomass Per Recruit

The selection Ogive routine method allowed estimating relative yield per recruit (Y′/R) and relative biomass per recruit (B′/Y). The relative yield per recruit (Y'/R) is used to determine the relationship between yield and fishing effort for different lengths of first capture. Using the imput parameters L_∞, K and M, the plots of Y'/R vs E (E=F/Z) and of B'/R vs E (E=F/Z) enable to estimate E_{max}, $E_{0.1}$ and $E_{0.5}$. Emax is the exploitation level which maximizes Y'/R, E0.1 is the level of exploitation at which the marginal increase in the relative yield per recruit is 10% of its value at E = 0, and E0.5 is the exploitation rate of reducing stock to half its virgin biomass [23].

2.3.7. Predictive Model of Thompson and Bell (1934)

This model is used to predict the effects of changes in fishing effort on future production and biomass from the historical data of fishery. It also incorporates the cost of catches. So, the model has become the basis for the development of the so-called bio-economic models for management decisions [15]. This model combines features of Beverton and Holt's relative yield per recruit (Y'/R) model with those of Virtual Population Analysis. This includes fishing mortalities by length group, the growth parameter (K) and the natural mortality factor by length group. The outputs are yields, biomass and values for 40 multipliers of fishing mortality (F) [22].

3. RESULTS

3.1. Growth Parameters

Chrisychthys nigrodigitatus could reach an asymptotic length of 24.15 cm with an average growth rate of 0.6 per year and the age of t_0 at -0.009 years. As for *Synodontis schall*, asymptotic length of 22.05 cm could be reached with an average growth rate of 0.73 per year and the age of t_0 at -0.012 years. The growth performance index recorded for *Chrisychthys nigrodigitatus* and *Synodontis schall* are similar with respective values of 2.544 and 2.550. As for longevity, value calculated for *Chrisychthys nigrodigitatus* is 5.00 and 4.11 for *Synodontis schall*.

3.2. Mortality and Exploitation Rates

Mortality parameters values estimated for *Synodontis schall* remain higher than those for *Chrisychthys nigrodigitatus*. Total mortality (Z) was 1.66 and 2.11, respectively for *Chrisychthys nigrodigitatus* and *Synodontis schall*. For the two species, fishing mortality values remain lower than natural mortality. As for exploitation rates, values registered for the two species remain inferior to the reference point of 0.5. However, the highest value of this parameter is observed for *Synodontis schall* (0.26) while the minimum is for *Chrisychthys nigrodigitatus* (0.19) (Figure 2).

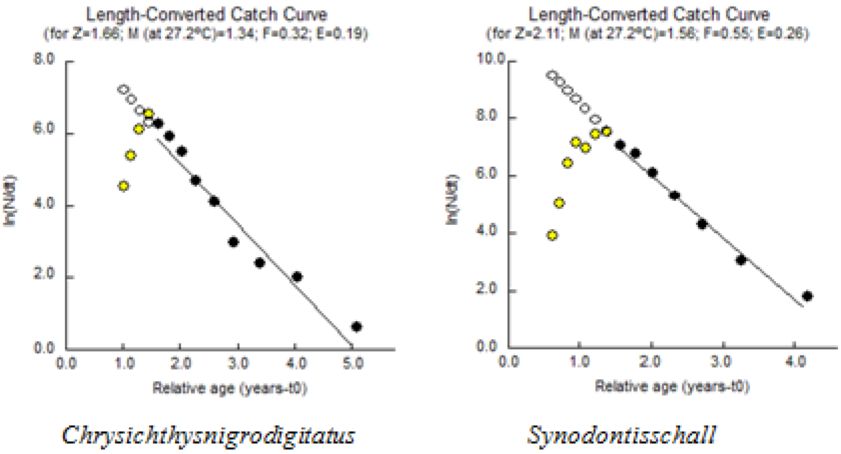


Figure2. *Linearized length-converted catch curve for estimation of mortality parameters and exploitation rates for Chrisychthysnigrodigitatus and Synodontisschall.*

3.3. Probability of Capture

For *Chrisychthys nigrodigitatus* and *Synodontis schall*, 25% of the fish are retained in gear respectively at 11.8 cm and 10.67 cm and 75% of them are also retained respectively at 12.3 cm and 11.67 cm. As for the lengths at first capture, corresponding to L_{50}, length at which 50% of the fish are retained by the gear, they are 12.05 cm for *Chrisychthys nigrodigitatus* and 11.17 cm for *Synodontis schall* (Figure 3).

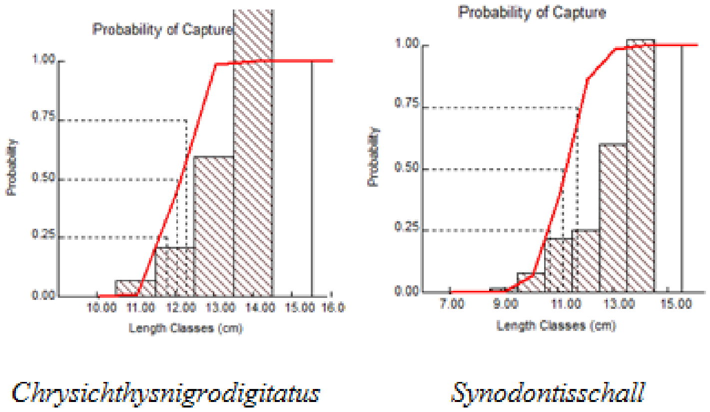


Figure3. *FiSAT II output of probability of capture for Chrisychthys nigrodigitatus and Synodontis schall*

3.4. Virtual Population Analysis (VPA)

Results of virtual population analysis indicate that, for the two species, fish population decrease with increase length class (Figure 4). The highest fishing mortality values are recorded between 13 cm and 17 cm. Inside this interval, fishing mortalities per class size are similar for *Chrisychthys nigrodigitatus*, whereas for *Synodontis schall*, mortality is highest in the class size [15.5-16.5[. The size class interval most abundant in the catches is [13.5-14.5[for the two species. This last class provides the main fraction of the stock biomass for *Synodontis schall* and secondarily for *Chrisychthys nigrodigitatus*. For all length-classes of the two species, natural mortality (M) remains higher than fishing mortality (F).

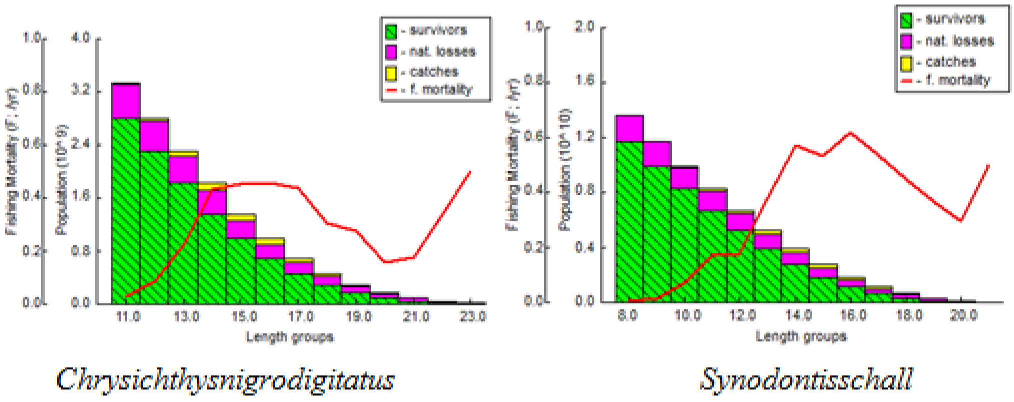


Figure4. *Virtual population analysis for Chrisychthys nigrodigitatus and Synodontis schall*

3.5. Yield and Biomass Per Recruit and Biological Reference Points

The results of Beverton and Holt's relative yield and biomass per recruit model on figure 5 showed that for *Chrisychthys nigrodigitatus* and *Synodontis schall*, the exploitation rate of reducing stock to half its virgin biomass (E0.5) were 0.329 and 0.359, respectively. As for exploitation rate considered as economic yield target (E0.1), values registered were 0.601 for *Chrysichthys nigrodigitatus* and 0.553 for the other species. For the two species, the exploitation level which maximizes Y'/R (Emax) is 0.699.These results also show that the current exploitation rates obtained in this work (E=0.19 for *Chrisychthys nigrodigitatus* and E=0.26 for *Synodontis schall*) remain lower than those indices.

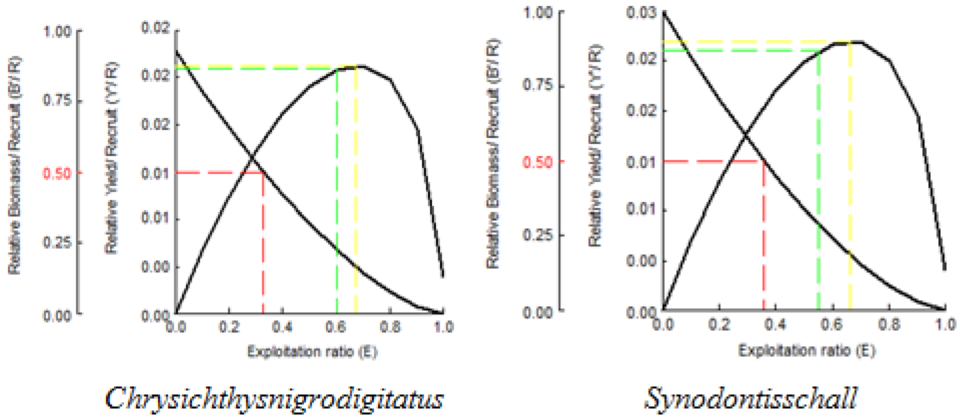
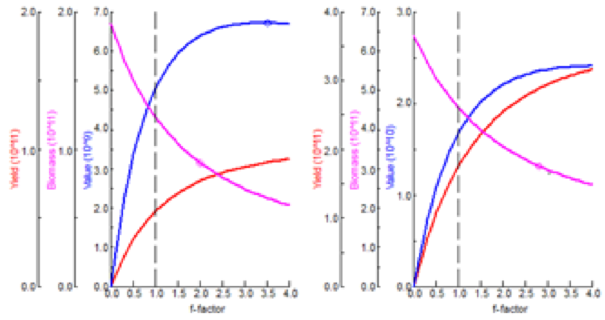


Figure5. Beverton and Holt's relative yield per recruit and relative biomass per recruit results produced through Ogive routine method for *Chrisychthys nigrodigitatus* and *Synodontis schall* (Red dashes= E0.5, Green dashes= E0.1 and Yellow dashes=Emax).

3.6. Thomson and Bell Prediction Analysis

Predictive model of Thompson and Bell allowed obtaining 40 multipliers of fishing mortality F. The level of fishing mortality in present work corresponds to the multiplier of F equal to 1. Figure 6 indicates that levels of maximization are visible only on biomass curves for the two species and on the value curve for *Chrysichthys nigrodigitatus*. Fishing mortality (F) reducing stock to half (50%) its virgin biomass is 1.8 and 2.5 times greater than current fishing mortality registered for *Chrysichthys nigrodigitatus* and *Synodontis schall*, respectively. The application of those fishing efforts (fishing mortalities) would lead to increase catches and economic values, respectively, around by 34.33% and 23.55% for *Chrysichthys nigrodigitatus*, while for *Synodontis schall*, catches would increase around by 57.86% and 37.81% for economic values. Another simulation indicates that for *Chrysichthys nigrodigitatus*, fishing effort (fishing mortality) providing the highest level of values is 3.4 times greater than the current fishing mortality, increasing accordingly catches by 63.45% but reducing negatively virgin biomass by 65.69%. Finally, fishing mortality providing the highest level of values for *Synodontis schall* and the maximum sustainable yield (MSY) for the two species are other four times greater than the current fishing mortality calculated.



Chrysichthysnigrodigitatus *Synodontisschall*

Figure6. *Yield, biomass and value curves produced through Thompson and Bell analysis for Chrysichthys nigrodigitatus and Synodontis schall*

4. Discussion

Growth parameters of the two siluriforms subject of this study compared with those obtained by other authors in Table 1 showed low values of asymptotic length (L_∞) as well as growth performance index (*Φ*') in this study for *Chrisychthys nigrodigitatus*. The growth rate (K) is generally close to values obtained by these authors. For *Synodontis schall*, on the other hand, asymptotic length, growth performance index and longevity generally remain close to values obtained in other localities. According to reference[24], differences among growth parameters for the same species in various geographic localities are due to variations in environmental conditions as well as sampling techniques and computations. However, the low value of the asymptotic length (L_∞) for *Chrisychthys nigrodigitatus* in this work is an indication that catches are composed of small sizes. As for the growth performance index (*Φ'*) registered for *Chrisychthys nigrodigitatus* and *Synodontis schall*, mean values of this parameter have been reported for some important fish in Africa within the range of 2.65-3.32 [25]. In this study, the *Φ'* estimated for the two species remain slightly lower than the minimum required 2.65, indicating low growth performance for them. The reference [26] suggested that linear growth may vary from one water body to another, because environmental factors such as productivity of the areas and availability of food may change. Some authors also point out the changes in physical and chemical characteristics of the waters [27]. It's also important to notice that Harmattan period in northern Côte d'Ivoire, lasting from 3 to 5 months, is responsible for a considerable drop in the temperature of the environment. This could limit the growth of fish [28].

Table1. *Growth parameters of Chrisychthys nigrodigitatus and Synodontis schall in comparison to populations from other fisheries*

Species	Locality	L∞	K	t_0	Ø'	tmax	References
	Solomougou Dam Lake – Côte d'Ivoire	24.15	0.6	-0.009	2.544	5.00	Currentstudy
C.nigrodigitatus	Lake Buyo– Côte d'Ivoire	63.33	0.76	-0.17	3.48	4	Goli Bi et al., (2019)
	Ghana	44.5	0.65	-0.22	3.12	-	Ofori-Danson, 2002
	Lower cross river - Nigeria	120.23	1.50	0.00	4.336	-	Udoh et al., 2015
	Solomougou Dam Lake – Côte d'Ivoire	22.05	0.73	-0.012	2.550	4.11	Currentstudy
S. schall	Tovè River (Benin)	21.84	0.93	-0.49	2.64	3.22	Djidohokpin et al., 2017
	Ouémé River (Benin)	32.00	0.32	-0.50	2.52	9	Chikou (2006)

Total mortality, natural mortality, fishing mortality and exploitation rate registered for *Synodontis schall* are higher than those calculated for *Chrisychthys nigrodigitatus*. This reflects a higher level of mortality on the stock of *Synodontis schall* in this fishery than on that of *Chrisychthysnigrodigitatus*. Exploitation rate values obtained for *Chrisychthys nigrodigitatus* and *Synodontis schall* are respectively 0.19 and 0.26. According to reference [20], an exploitation rate of 0.5 indicates an optimal exploitation of the stock. Below this value, the population is underexploited. Consequently, the stocks of these species remain underexploited.

For the two species, we noticed that natural mortality was found to be higher than fishing mortality.

The length at first capture (L_{50}) estimated in this study was 12.05 cm for *Chrisychthys nigrodigitatus*and 11.17 cm for *Synodontis schall*. It is reported that in Ivorian waters, female's length at first sexual maturity is reached at variable sizes for *Synodontis schall* (184 mm, 131 mm or 145 mm of standard length) [29]. For *Chrisychthys nigrodigitatus*, on the other hand, lengths of 20-21 cm and 14-15 cm have been reported for the smallest mature specimens, respectively, for females and males [30]. The estimated lengths at first capture remain lower than these sexual maturity lengths. This suggests that fish are caught before reaching the matured stage. It is important to notice that, on the Solomouogu Dam Lake, fishing is practiced throughout the year. But this activity remains little practiced during 5 to 6 months during the year. Fishermen exploiting this fishery are of foreign origin. So, they return each year to their country, especially during the rainy season for family visits and for agricultural activities [31]. This represents a recovery period for the fishery. This could explain the fact that despite the presence of small specimens in catches, exploitation levels remain so low.

The results of Beverton and Holt's relative yield per recruit (Y′/R) obtained through Ogive routine method for *Chrisychthys nigrodigitatus* and *Synodontis schall* gave value of exploitation rate that produce the maximum sustainable yield Emax = 0.699 for the two species. The present exploitation rate registered was E=0.19 for*Chrisychthys nigrodigitatus* and E=0.26 for *Synodontis schall*, which do not exceed the Emax. This is an indication that stocks of these two species was not overexploited in the Slomougou Dam Lake, confirming the interpretation of current exploitation rates lower than reference of 0.5. So, risks to surpass the maximum sustainable yield are not obvious. However, management of fishery considering only Emax level could critically decrease the biomass. Relative biomass per recruit results stated that exploitation rate of reducing stock to half its virgin biomass for *Chrisychthys nigrodigitatus* and *Synodontis schall* (E0.5) were 0.329 and 0.359, respectively. These values are higher than current exploitation rates. So, additional exploitation of their biomass is possible.

Predictive model of Thompson and Bell showed that fishing mortality (F) reducing stock to half its virgin biomass is 1.8 and 2.5 times greater than current fishing mortality registered for *Chrysichthys nigrodigitatus* and *Synodontis schall*, respectively. The application of those fishing efforts (fishing mortalities) would lead to increase catches and economic values around by 34.33% and 23.55%, respectively for *Chrysichthys nigrodigitatus*, while for *Synodontis schall*, catches would increase around by 57.86% and 37.81% for economic values.

5. CONCLUSION

The stocks of the two most abundant siluriforms fish in catches from the Solomougou Dam Lake are under-exploited. So, additional exploitation of their biomass is possible. However, the estimated lengths at first capture are lower than sexual maturity lengths suggesting that fish are caught before reaching the matured stage. Thus, any policy of increasing fishing effort in order to increase catches should imperatively be carried out with a readjustment of the selectivity of the fishing gear. This will contribute to a better renewal of their stocks.

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