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The first data on the population parameters of the main fish species in man-made Lake Buyo (River Sassandra, Côte d'Ivoire)

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SUMMARY

The growth parameters and the exploitation rate of the main 9 fish species found in the lake of the Buyo dam was studied from July 2017 to June 2018. The monthly frequency data for lengths obtained from experimental and commercial fisheries were analysed using the FiSAT II software and its sub-program ELEFAN for the evaluation of population parameters. The asymptotic length (L_∞) varies from 63.33 cm for *Chrysichthys nigrodigitatus* to 15 cm for *Synodontis koensis*. The specific growth rate (K) is higher (0.9 year^{-1}) in *Malapterurus electricus* and lower (0.21 year^{-1}) in the species *Schilbe mandibularis*, while the growth performance index (φ') calculated from 3.48 in *Chrysichthys nigrodigitatus* to 2.04 in *Tilapia zillii*. The fishing mortality (F) and exploitation rate (E) calculated are below the optimal exploitation rate for most species. The recruitment pattern is a continuous model with a single peak and reveals a recruitment period in the months of May, June, August and October. According to the exploitation predictions, the species *O. niloticus, M. electricus, C. nigrodigitatus, D. rostratus* and *L. niloticus* have an exploitation rate E respectively 0.35; 0.46; 0.27; 0.41 and 0.31 higher than the optimum exploitation rates Eop (respectively 0.29; 0.33; 0.37; 0.28 and 0.27), which would mean that the stock of these species in the fishery is already reduced to more than 50% of its untapped biomass; therefore overexploited. Our study provides the first data on the population parameters of the main fish species from the Lake Buyo. These data could contribute to establish a sustainable management plan for fisheries resources only in lake Buyo.

INTRODUCTION

In Côte d'Ivoire, like in most developing countries, fish is the main source of animal protein (Ticheler, 2000). As a result, stocks of fish populations are decreasing due to extensive and uncontrolled exploitation of this animal resources (Lalèyè *et al*., 2007). Indeed, some fisheries have shifted from artisanal exploitation to industrial exploitation, from subsistence to commercial activity (Njiru *et al*., 2005, Kantoussan, 2007), resulting in dwindling catches observed in some fisheries, in the lakes Buyo

(Vanga *et al.*, 2002), Kossou (Da Costa and Konan, 2005), see their depletion (Vanga, 2004).

This situation today calls for the need to evaluate the influence of these pressures on the production of these lakeside systems. This means having knowledge of the composition of the catches, according to age or size, a more detailed description of the stock. In addition, growth and exploitation parameters are essential for a good understanding of general biology and population dynamics.

Lake Buyo is one of the most recent dam in Côte d'Ivoire after Lake Soubré in 2017. Since its creation, this lake has been the subject of several research projects (Traoré, 1996; Vanga, 2001; Vanga *et al.*, 2002; Ossey *et al.*, 2008 ; Kouamé, 2010). These works focused on the continental fisheries, the socioeconomic consequences of natural resource management, the impact of fishing on fish availability in the lakeside regions, the analytical study of chemical characteristics, and the biological diversity and dietary habits of some species. Previous work (Vanga, 2001; Kouamé, 2010) carried out on lake Buyo reported the predominance of Cichlidae and Claroteidae as well as that of *Oreochromis niloticus*, *Tilapia* sp. and *Chrysichthys* sp. in the catches from the Buyo Lake. The present study thus lays the foundations for the dynamics of the main fish population of the Buyo reservoir. There are many studies but there are currently no data available on the population dynamics of the species in this lake. It aims to estimate growth parameters and to assess the level of exploitation of the main species landed. The results of this work will contribute to the implementation of measures to better management of the stock and thus ensure the sustainability of this highly valued fishery resource in Côte d'Ivoire.

MATERIALS AND METHODS

Study area

The Lake of Buyo (Fig. 1) was built along the edge of the Tai National Park, 4 km downstream from the confluence of N'Zo and Sassandra, drowning approximately 8400 hectares of forest in the park (OIPR, 2006). According to Ossey *et al.* (2008), Lake Buyo occupies a catchment area of 46250 Km^2. This lake is between 06°14' and 07°03' north latitude and 06°54' and 07°31' west longitude and covers an area of 920 km^2 (Kouamé, 2010).

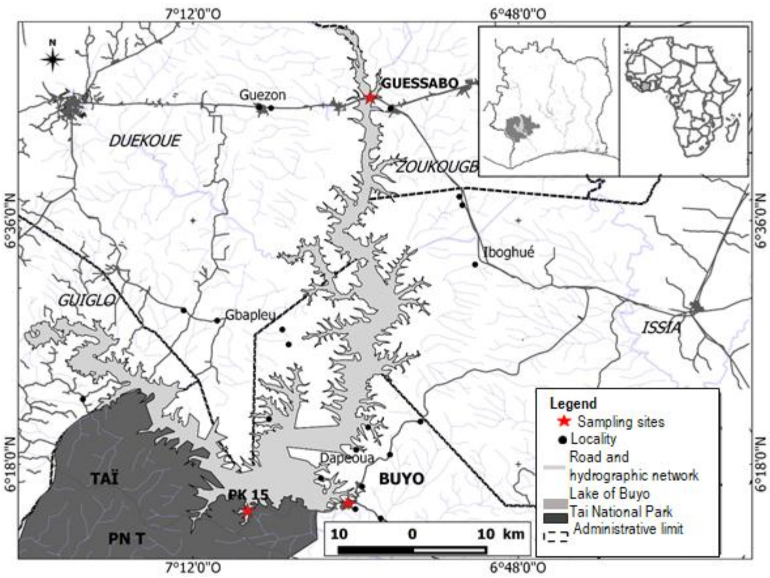

Fig. 1: Location of the Lake of Buyo and location of the sampling stations ★

The hydrological regime of this lake depends on the Sassandra River, the N'Zo primary tributary and rainfall in the region (Traoré and Konan, 1989). Three study stations such as Guessabo, Buyo city and PK15 have been selected in this study according to their proximity to the lake, the existence of a commercial exploitation of fish, their easy accessibility by road in all seasons.

Fish sampling and data collection

Sampling was carried out in three study stations (Guessabo, Buyo City and PK15) (Fig. 1). Fish were collected each month from July 2017 to June 2018. Specimens examined were from commercial and experimental fisheries. Commercial fish were caught using gillnets, seines and traps. Those from the experimental fishery were caught only with gillnets for a total of 3884 specimens. They were chosen on the basis of numerical abundance and were identified using dichotomous identification keys (Paugy *et al.*, 2003a and b). On each specimen, the standard length expressed in cm was determined using an ichtyometer graduated.

Data processing

Determination of growth parameters (L_∞, K, φ', Rn, t_0, T_{max})

Length was grouped into 1 cm intervals for small specimens and 2-4 cm for large specimens (Kantoussan, 2007; Tah, 2012) to allow for a representative number of individuals. Frequency distribution was analysed using FiSAT II software (Gayanilo *et al.*, 2002). The FiSAT II ELEFAN I program was used to estimate the growth parameters (L_∞) and (K) according to the model of Von Bertalanffy (Gayanilo *et al.*, 2002) which is as follows:

$$Lt = L_\infty\ (1 - e^{-k\,(t-t0)})$$

Where:

Lt = length of fish at age t considered (cm); L_∞ = asymptotic length (cm), length that the species could reach if it continues t0 live and grow indefinitely; K = growth coefficient or growth rate characterizing the speed with which the species grows towards L_∞ ($year^{-1}$); t0 = theoretical age of the fish when its length is zero (year). The parameter t_0 was obtained from the empirical equation of Pauly (1979):

$$Log_{10}(-t_0) = -0.392 - 0.275 log_{10} L_\infty - 1.038 log_{10} K$$

The method consists of revealing the model of Length frequency distributions and validating the growth curves whose plots, overlapping with those of the distributions themselves, take into account the large number of this model. The distributions and the growth curves selected are then presented in the same graph.

The performance index (φ') was evaluated from the growth parameters L_∞ and K by **Pauly and Munro**'s relation (**1984**) which is defined as follows:

$$\varphi' = log_{10} K + 2 log_{10} L_\infty$$

The quality index of the adjustement (Rn) was determined automatically by the FiSAT II software (Gayanilo *et al.*, 2002).

Longevity or maximum age (T_{max}) was calculated with Pauly's formula (1985):

$$T_{max} = 2.9957 / k$$

Evaluation of the exploitation rate of the main species (Mortality, recruitment, yield, virtual populations).

Mortality and exploitation rate

The growth curve obtained was used to convert the length frequencies into age-class (Pauly, 1984) in order to determine the instantaneous mortality coefficients (M and F).

The instantaneous total mortality coefficient (Z) was estimated by the catch curve method according to the lengths used with the FiSAT II software with:

$$\mathbf{N_{t+1} = N_t e^{-Z}}$$

Where:

Nt = number of fish at time t; Nt + 1 = number of fish at time t + 1

The construction of this catch curve took into account L_∞, K, t_0 (t_0 = 0) and the mean annual temperature (T° C) for the plot of a graph with Log Nt in ordinate, t in abscissa and Z = - b the slope of the regression line, according to the following formula:

$$\mathbf{LogN_t = a + bt}$$

Where:

Nt = number of individuals in length class t; a = intercept at the origin of the regression line;

b = slope of the regression line

The final (Log Nt) graph gives the instantaneous mortality rates (Z, M and F) and exploitation rates (E).

The natural mortality (M) was calculated using the method of Pauly (1980) which is based on the following facts: there is obviously an inverse relationship between M and the maximum length observed itself partly related to longevity and K coefficient. This relationship is however not close enough to allow only an evaluation of M. This is why Pauly (1980) introduced the notion of average annual temperature of the medium. The equation is:

$$\mathbf{Log_{10}M = -0.0066 - 0.0279Log_{10}L_\infty + 0.6543Log_{10}K + 0.463Log_{10}T}$$

Where :

T = average annual temperature of the medium. In this study, the calculated annual temperature is 30.3 °C (*Obs. Person.*)

According to **Pauly (1980),** this method of estimating M is widespread in tropical regions.

Knowing Z and M, the fishing mortality coefficient (F) was obtained by difference $(\mathbf{F = Z - M})$ and the exploitation rate (E) which is the **F / Z** ratio $[\mathbf{E = F / Z = F / (F + M)}]$ was also determined. The exploitation rate indicates whether the stock is slightly (E < 0.5) or highly (E > 0.5) exploited, under the assumption that the exploitation of the stock is optimal when F = M or E = 0.5 (**Gulland, 1971**).

The Chi-square test was used here to compare the fishing mortality coefficients to the theoretical value 1.

Recruitment period

Using the growth parameters L_∞, K and t_0, another program of FiSAT II (version 1.2.2) to reconstructs a relative frequency histogram of births for each month. This graph, which shows the monthly changes in the recruitment of young fish, was obtained by retro projection of length-frequency data along the time axis (Moreau and Cuende, 1991). The normal distribution of the recruitment pattern was determined by NORMSEP (Pauly and Caddy, 1985) in FiSAT II.

Yield and biomass per recruit

The reference points of Beverton and Holt (1966) for optimal fisheries management are $E_{0.1}$; $E_{0.5}$ and E_{max} represented on the curves of variation of the relative yield (Y '/ R) and relative biomass per recruit (B' / R). These different exploitation rates are respectively defined as being: (1) the exploitation rate for which the marginal increase in the relative yield per recruit is 1/10 or 10% of its value; (2) the exploitation rate that results in a reduction of the untapped stock biomass by 50% and (3) the exploitation rate that produces a maximum yield per recruit (E_{max}).

Virtual Population Analysis (VPA)

Virtual population analysis are methods that allow the population to be reconstructed from total catch data according to age or length. VPA was performed uing FiSAT II with the aid of modified Jones and Van Zalinge (1981) routine adapted to length frequencies.

RESULTS

Growth parameters

The growth parameters and maximum length captured for the main nine fish species from the lake of Buyo are shown in Table 1. The estimated growth curves for these species are shown in Fig. 2. It can be seen that the maximal length observed for the nine species is all less than their respective asymptotic length (L_∞). Therefore, it is observed that within the same genus the value of L_∞ is closer, in Cichlidae except in *Oreochromis niloticus*.

Table 1: Growth parameters of the main fish species from Buyo Lake from July 2017 to June 2018. n = number of specimens .

Parameters	*Oreochromis niloticus* (n=819)	*Chrysichthys nigrodigitatus* (n=798)	*Synodontis koensis* (n=474)	*Distichodus rostratus* (n=342)	*Malapterurus electricus* (n=314)	*Tilapia zillii* (n=281)	*Lates niloticus* (n=275)	*Schilbe mandibularis* (n=279)	*Tilapia hybrid* (n=302)
LS max obs (cm)	29.5	57	13.5	24.5	28.5	17	36	26.5	17
L_∞ (cm)	32.77	63.33	15	27.22	31.66	18.88	40	29.44	18.88
K ($year^{-1}$)	0.6	0.76	0.63	0.61	0.9	0.31	0.5	0.21	0.8
φ'	2.81	3.48	2.15	2.65	2.95	2.04	2.9	2.26	2.45
Rn	0.3	0.26	0.45	0.74	0.3	0.32	0.34	0.35	0.25
t_0 (year)	-0.26	-0.17	-0.31	-0.57	-0.17	-0.61	-0.3	-0.8	-0.22
T_{max} (year)	5	4	5	5	4	10	6	15	4

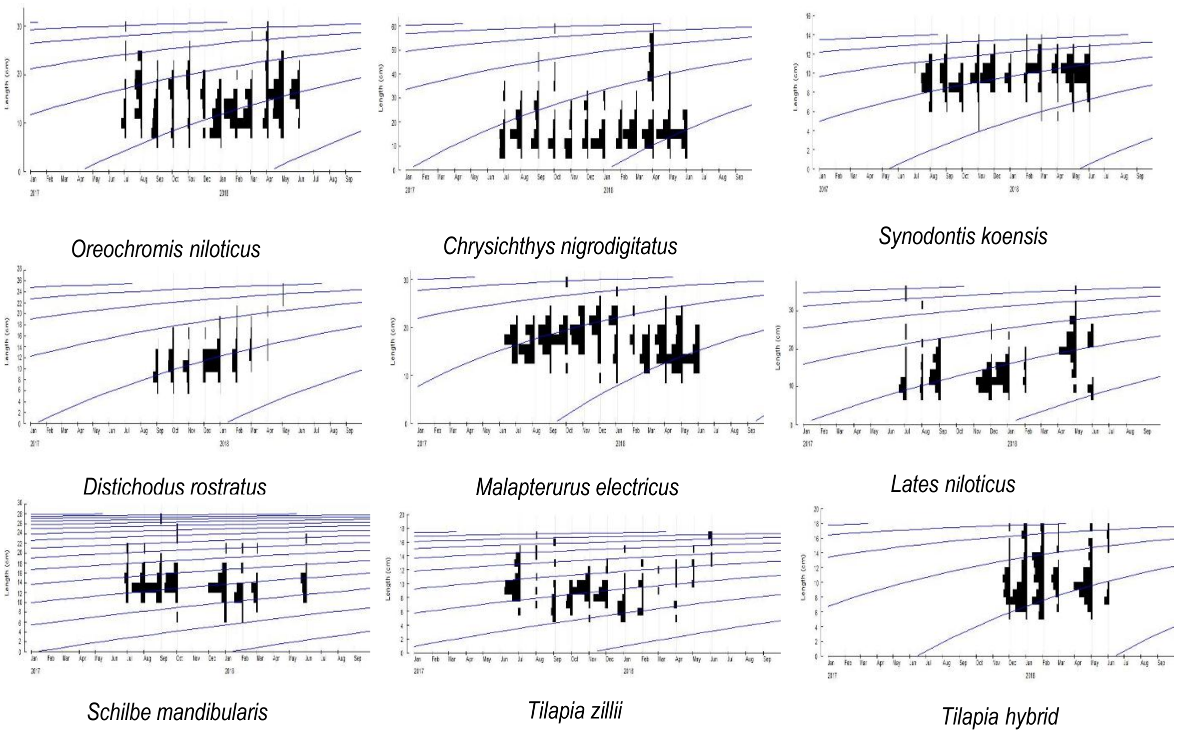

Fig. 2: Modeling of growth of the main fish species from Buyo Lake according to Von Bertalanffy model. In black: the positive value of the frequencies observed and theoretical sizes; blue lines overlapping on lenght frequency histograms: growth curves indicating cohorts.

The growth performance index (φ') is relatively high in this species. The specific growth rate (K) is higher in the species *Malapterurus electricus* (0.9 $year^{-1}$), *Tilapia hybrid* (0.8 $year^{-1}$) and *Chrysichthys nigrodigitatus* (0.76 $year^{-1}$). Of the nine species, *C. nigrodigitatus* has the highest growth performance (φ') while the other species have a performance index which is in the same range. When the theoretical age of the fish at length zero (t_0) is high, its longevity (or T_{max}, maximum age) is shorter. This is the case for most species, except for *Tilapia zillii* and *Schilbe mandibularis*, which have a low t_0 (-0.61 and -0.8 year) with a high longevity (10 and 15 years).

Exploitation parameters

Instantaneous coefficient of mortality and exploitation rate

The catch curves according to the lengths obtained from the different populations studied are illustrated in Fig. 3.

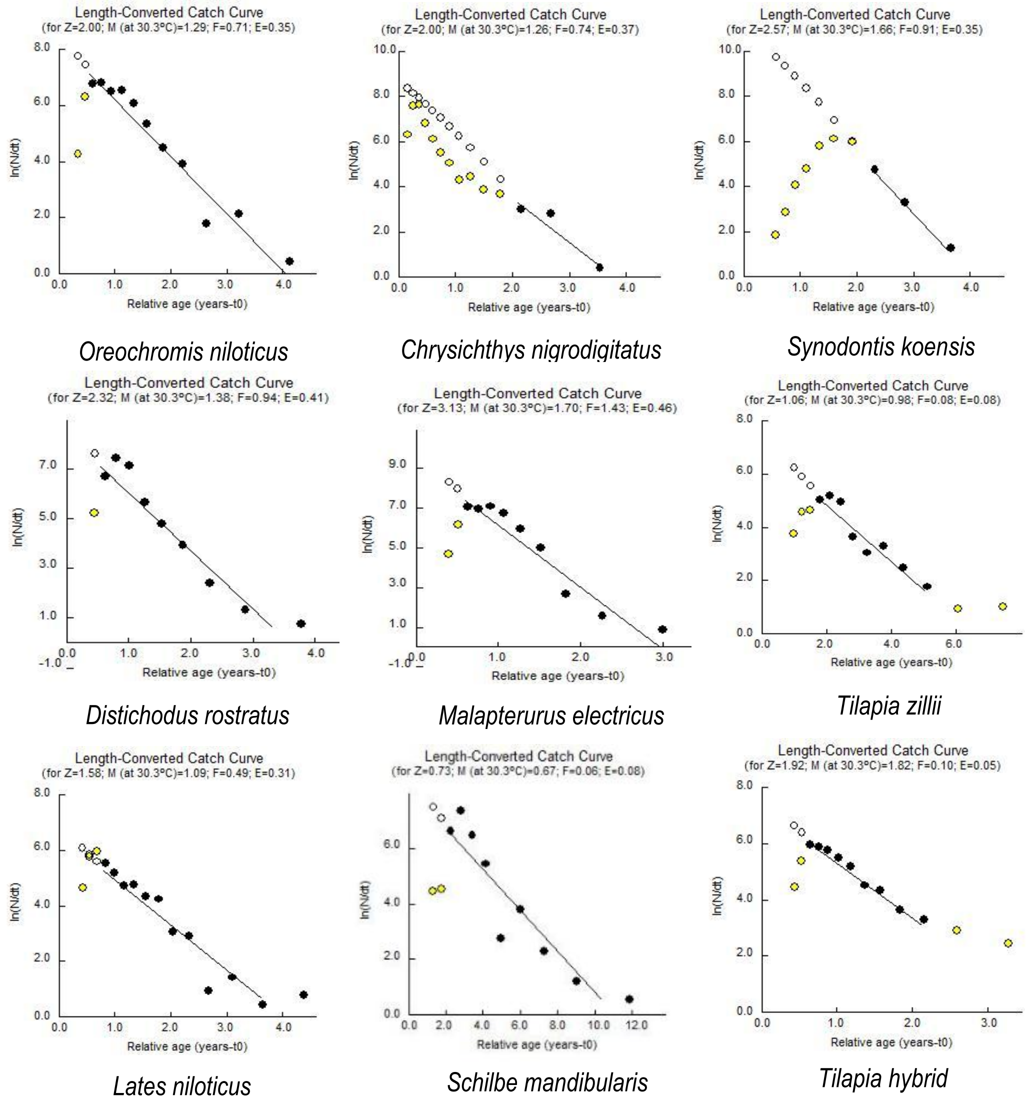

Fig. 3: Linear catch curve of the main species from the Lake of Buyo. The black dots are those used for calculating (Z) through a least squares linear regression; the yellow dots are not taken into account either too close or too far from the asymptotic length; and the white dots are the extrapolated points of the curve according to the lengths.

The values of the total mortality (Z), the natural mortality (M) at the average temperature of 30.30 °C, the fishing mortality (F) and the exploitation rates of the nine main fish species are shown in Table 2. For all the species studied, the natural mortality coefficients (M) are greater than their respective fishing mortality coefficients (F). Natural mortality (M) is, however, higher in *Tilapia hybrid* (1.82 per year) and lower in *S. mandibularis* (0.67 per year). The fishing mortality (F) is 1.43 per year in *M. electricus*. In addition, this species has the highest total mortality rate (Z) (3.13 per year). However, the species *S. koensis* and *D. rostratus* have a fishing mortality coefficient very close to 1 ($p > 0.05$, chi-square test) with their relatively high Z respectively 2.57 and 2.32 per year. As for the exploitation rate (E), it is closer to the theoretical value 0.5 for *D. rostratus* species (0.41) and *M. electricus* species (0.46).

Recruitment

The histograms (Fig. 4) show the monthly changes in the recruitment intensity of juveniles fish of the main species entering the lake of Buyo. The appearance of young fish in the water body is regular and year-round in this lake reaching a maximum level in October for *O. niloticus*, April for *C. nigrodigitatus*, May for *S. koensis* and *L. niloticus*, June for *D. rostratus* and *T. hybrid*, August for *M. electricus, T. zillii* and *S. mandibularis*.

Table 2: Exploitation parameters of the main fish species from Lake Buyo from July 2017 to June 2018. n = number of specimens

Parameters	*Oreochromis niloticus* (n=819)	*Chrysichthys nigrodigitatus* (n=798)	*Synodontis koensis* (n=474)	*Distichodus rostratus* (n=342)	*Malapterurus electricus* (n=314)	*Tilapia zillii* (n=281)	*Lates niloticus* (n=275)	*Schilbe mandibularis* (n=279)	*Tilapia hybrid* (n=302)
M ($year^{-1}$)	1.29	1.26	1.66	1.38	1.7	0.98	1.09	0.67	1.82
F ($year^{-1}$)	0.71	0.74	0.91	0.94	1.43	0.08	0.49	0.06	0.1
Z ($year^{-1}$)	2	2	2.57	2.32	3.13	1.06	1.58	0.73	1.92
E	0.35	0.37	0.35	0.41	0.46	0.08	0.31	0.08	0.05

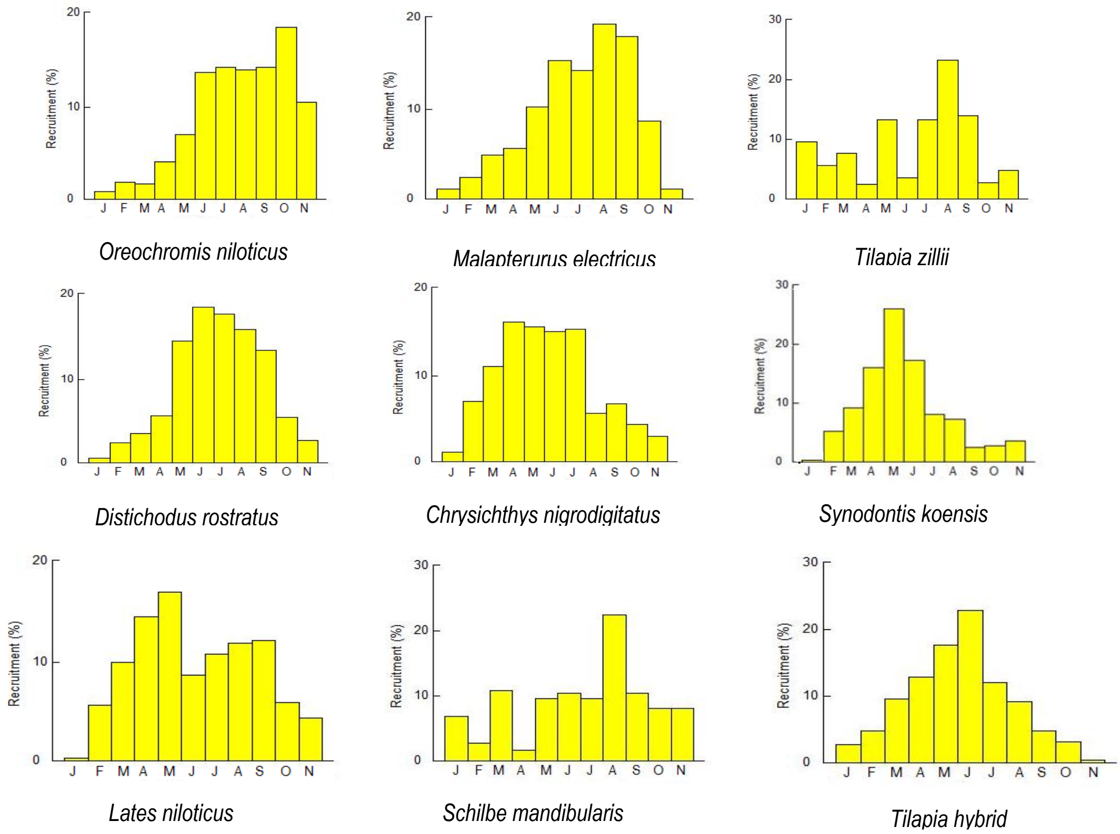

Fig. 4: Recruitment model of the main species from the Lake of Buyo

Relative yield (Y'/ R) and relative biomass per recruit (B' / R)

The relative yield curves (Y '/ R) and relative biomass per recruit (B' / R) for fixed values of Lc / L∞ and M / K are plotted using the FiSAT II software and allowed the determination of the biological references points for the fish populations studied (Table 3). This table shows that the optimal exploitation rate ($E_{0.5}$) of *O. niloticus* (E= 0.35> $E_{0.5}$= 0.29), *M. electricus* (E= 0.46> $E_{0.5}$= 0.33), *C. nigrodigitatus* (E= 0.37> $E_{0.5}$= 0.27), *D. rostratus* (E= 0.41> $E_{0.5}$ = 0.28) and *L. niloticus* (E= 0.31> $E_{0.5}$= 0.27) is reached. Fig. 5 shows for the 9 main species of fish exploited from the lake of the Buyo dam, the plotting of Y '/ R on E (=F / Z) and (B' / R) on E, which allow the estimation of E_{max}, $E_{0.1}$ and $E_{0.5}$ biological reference points.

Table 3: Summary of the analysis of the relative yield per recruit of the main fish species exploited from the Lake of Buyo.

Species	**Exploitation rate**					
	L_c/L_∞	**M/K**	**$E_{0,1}$**	**$E_{0,5}$**	**E_{max}**	**E = F/Z**
Oreochromis niloticus	0.25	2.15	0.41	**0.29**	0.49	**0.35**
Synodontis koensis	0.57	2.63	1	0.40	1	0.35
Malapterurus electricus	0.38	1.88	0.52	**0.33**	0.61	**0.46**
Chrysichthys nigrodigitatus	0.17	1.65	0.36	**0.27**	0.44	**0.37**
Distichodus rostratus	0.26	2.24	0.41	**0.28**	0.50	**0.41**
Lates niloticus	0.19	2.18	0.36	**0.27**	0.44	**0.31**
Schilbe mandibularis	0.33	3.19	0.51	0.32	0.64	0.08
Tilapia hybride	0.34	2.27	0.45	0.31	0.59	0.05
Tilapia zillii	0.36	3.16	0.56	0.33	0.70	0.08

In bold: species with an exploitation rate E close to the optimal exploitation rate $E_{0.5}$ or the maximum exploitation rate E_{max}

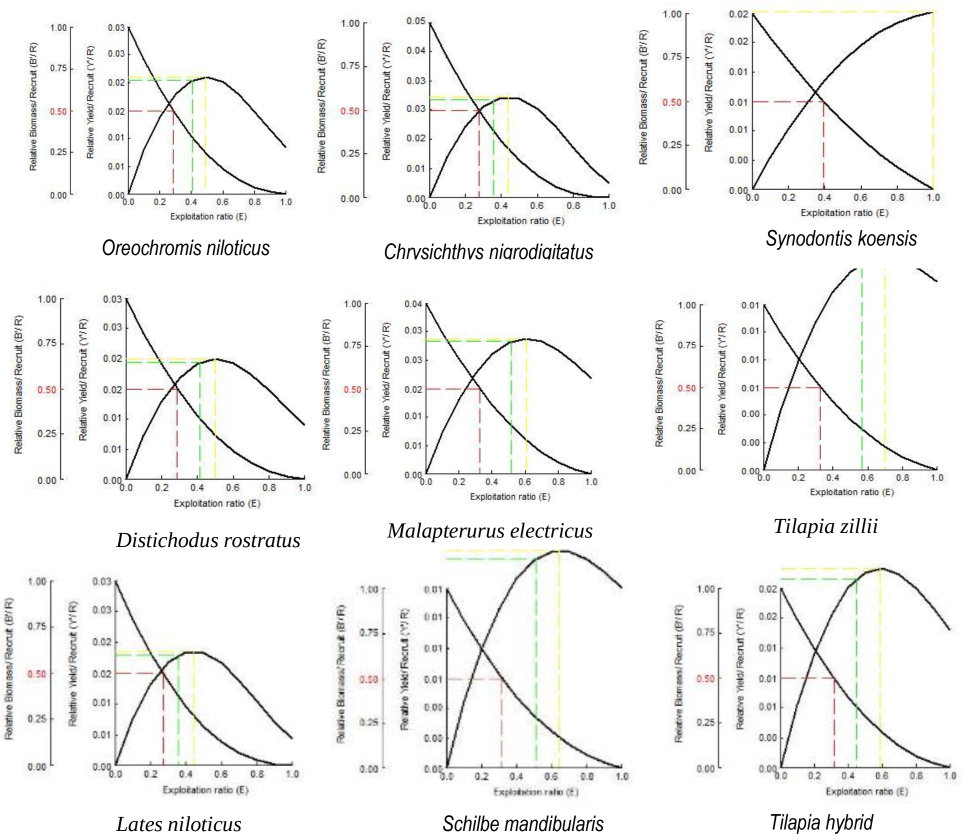

Fig. 5: Curve showing the variation in relative yield per recruit (Y '/ R) and relative biomass per recruit (B' / R) as a function of the exploitation rate E for the main populations exploited from the Lake of Buyo.

Virtual population analysis

The growth and exploitation parameters made it possible to establish the histograms of the virtual populations of the 9 main species of fish from the lake at the Buyo dam using FiSAT (Fig. 6). According to the reconstruction of the population represented in Fig. 6, it appears that the lost due to natural causes are higher in juveniles than in the adult population.

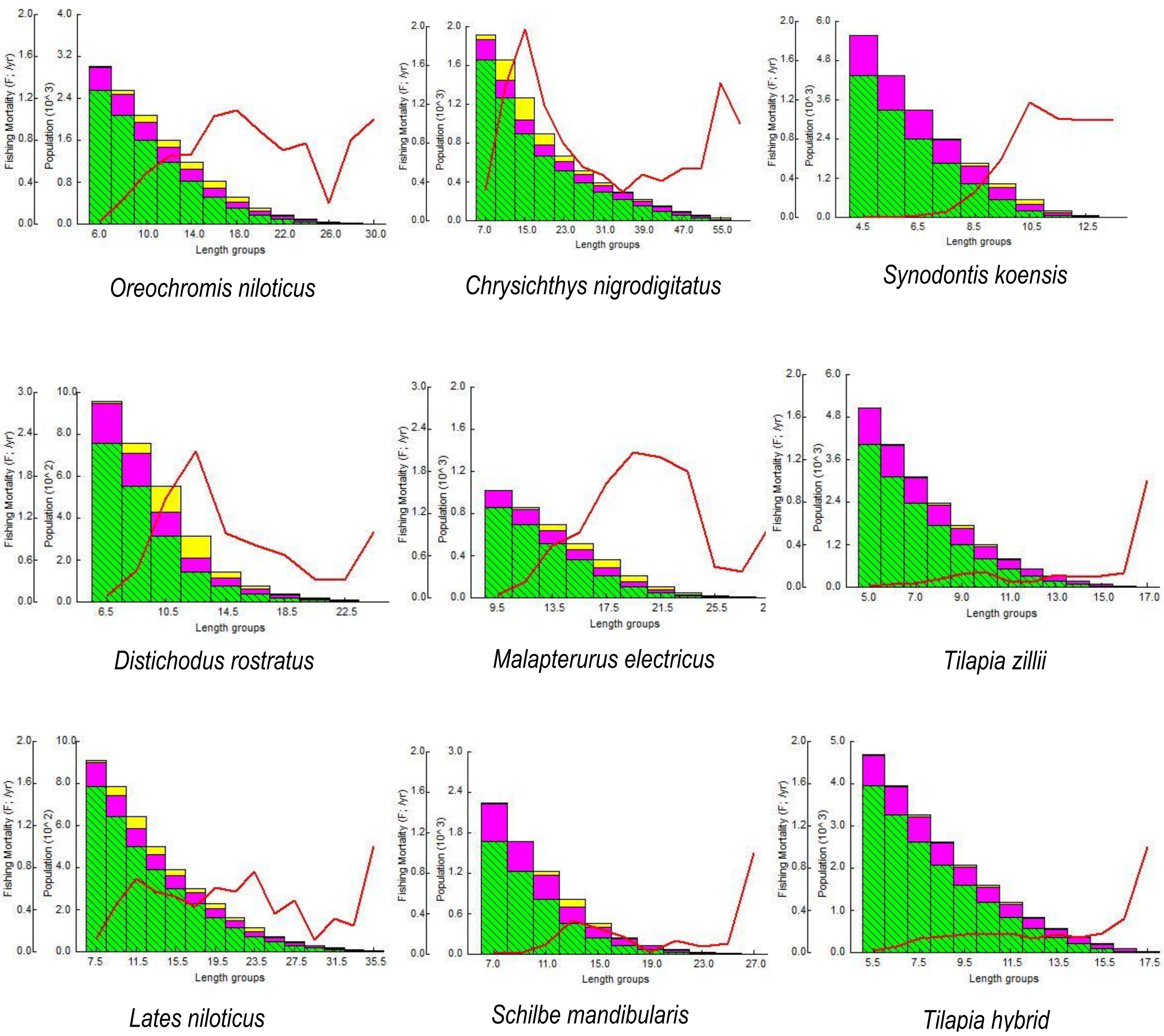

Fig. 6: Histograms of virtual populations based on the length of the main fish species landed at Lake of Buyo. In green: survivors; in pink: natural losses; in yellow: losses by catch; pink line: fishing mortality

As for the one lost to catches, it is more found in individuals of length between 10 and 18 cm for *O. niloticus*; 11 and 19 cm for *C. nigrodigitatus*; 9.5 and 10.5 cm for *S. koensis*; 10.5 and 12.5 cm for *D. rostratus*; 13.5 and 19.5 for *M. electricus*; 9 and 10 cm for *T. zillii*; 9.5 and 15.5 cm for *L. niloticus*; 12 and 15 cm for *S. mandibularis*; virtually absent in *T. hybrid*. The analysis of the graph reveals that the highest fishing mortality rate (≈1.1 / year) would be observed for fish of length between 17 and 18 cm for *O. niloticus*; 13 and 15 cm with a rate of about 2 / year for *C. nigrodigitatus*; 10 and 10.5 cm with a rate of about 1.2 / year for *S. koensis*; 11.5 and 12.5 cm with a rate of about 2.1 / year for *D. rostratus*; 18.5 and 19.5 cm with a rate of about 2.1 / year for *M. electricus*; 22.5 and 23.5 cm with a rate of about 0.7 / year for *L. niloticus*

DISCUSSION

The majority of maximum lengths (LS) measured in species from the Lake of Buyo are less than the value of the asymptotic length (L_∞). This means that the fish is caught before reaching their infinite length. This observation is confirmed by the small number of bigger sizes. The L_∞ values of the fish species studied from Lake Buyo are higher than those obtained by Tah *et al*. (2010) in Lake Ayamé I in Côte d'Ivoire, Niyonkuru *et al*. (2003) in Lake Nokoué in Benin, Baijot and Moreau (1997) in the Tanguiga reservoir in Burkina Faso for species such as *Chrysichthys nigrodigitatus* (63.33 cm in Buyo, 46 cm in Ayamé I, 26 cm in Nokoué) *Oreochromis niloticus* (32.77 cm in Buyo, 17.6 cm in Tanguiga), *Schilbe mandibularis* (29.44 cm in Buyo, 29 cm in Ayamé I). However , higher L_∞ values (35.5 cm) were observed by Tah *et al*. (2010) for *O. niloticus* in Ayamé Lake I. Abowei and Hart (2007) deduced that the observed differences in maximum Length in *C. nigrodigitatus* in Nigeria's lower rivers is due to overexploitation, environmental pollution and fishery degradation. In our case, this variation is due to overexploitation and natural predation.

In addition, the calculated growth performance index (φ') *of O. niloticus, D. rostratus, M. electricus and L. niloticus* are 2.81; 2.65; 2.95 and 2.90 respectively. These values are in the range ($2.65 < \varphi' < 3.32$) proposed by Baijot and Moreau (1997) for African fish. For these authors, such performance index values are attributed to reputable stocks of tropical slow-growing fish. *O. niloticus* and *C. nigrodigitatus* show the highest growth performance index (2.81, 3.48) compared to those reported for the same species (2.78, 2.71) in Lake Ayamé I, in Nigeria and Benin (3.10, 3.29, 2.95 respectively) for *C. nigrodigitatus*. According to Tah *et al*. (2010), a rapid growth rate reveals a defensive mechanism against predators.

Natural mortality of major species is higher than fishing mortality. These results indicate that stocks of these species are more affected by natural predation than by fishing. This trend has also been observed by Tah *et al*. (2010) at Lake Ayamé I and Abowei and Davies (2009) in the lower river in the Niger Delta in Nigeria. In addition, the M / K value greater than 2 for some species confirms the preponderance of natural predation as a key factor in the high natural mortality observed (Moreau *et al*., 2006). This trend was reported by Villanueva (2004) in four other African waters (Sine Saloum in Senegal, Gambia estuary, Nokoué lagoons and Ebrié). The exploitation rate values (E) are below the optimum exploitation rate ($E_{op} = 0.5$) recommended by Gulland (1971). These results showed that the main species found in the Lake Buyo appear to be underexploited. These results are consistent with those of Tah (2012) in Lake Ayamé I with the exception of *Schilbe mandibularis*, which is overexploited in Lake Ayamé I. In addition, in species *O. niloticus, M. electricus* , *C. nigrodigitatus, D. rostratus* and *L. niloticus,* the current exploitation rates E is higher than the optimum exploitation rates Eop calculated by FiSAT, which would mean that the stock of these species in the fishery is already reduced to more than 50% of its untapped biomass; therefore overexploited.

Regarding recruitment, the peak recruitment (period of the predominance of juvenile specimens in the year) in these species is observed in April, May, June, August and October,. Indeed, this phenomenon occurs during the rainy season when trophic conditions become favorable for the growth of young fish (Koné, 2000).

These results are similar to those of Tah *et al*. (2010) and the work of several authors who have worked on tropical fish reproduction in Africa (Koné, 2000; Ouattara *et al*., 2008).

As for the virtual analysis of the populations, it shows that the mortality natural rate decreases progressively as the size of the fish increases. This could be explained by the fact that juveniles are more vulnerable to natural predation as indicated by Koné (2000).

Considering the results of this study, we recommend reducing fishing effort from April to June and from August to October, period where the recruitment of juveniles fishes into Buyo dam lake is very intense. Furthemore, this work draws attention to the need to focus in particular on the monitoring of species *O. niloticus, C. nigrodigitatus*, *L. niloticus*, *M. electricus* and *D. rostratus* whose the stocks in the fishery were already reduced by more than 50% of the unexploited biomass.

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