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Research Article

Growth, mortality and yield of *Sarotherodon melanotheron melanotheron* (Rüppell, 1852) in the Lake Nokoué and Porto-Novo Lagoon complex Benin, West Africa

Djiman Lederoun[1,*], Gildas Amoussou[1], Imaculé S. Baglo[1], Hermann Adjibogoun[1], Hamil Vodougnon[1,2], Jacques Moreau[3] and Philippe A. Lalèyè[1]

[1] Laboratory of Hydrobiology and Aquaculture, Faculty of Agricultural Sciences, University of Abomey-Calavi, Cotonou, Benin
[2] Laboratory of Animal Pathology, Microbiology and Immunology, University of Abomey-Calavi, Cotonou, Benin
[3] Department of Aquatic Environment, INP/ENSAT, Castanet Tolosan, France

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Abstract – The study evaluated some population parameters of *Sarotherodon melanotheron melanotheron* within a lagoon complex in southern Benin: Lake Nokoué and Porto-Novo Lagoon. Data on the total length, total weight, and sex were recorded monthly between January and December 2015 for 1,745 specimens captured by local fishermen. The asymptotic length $L\infty$ was estimated at 24.68 cm. The growth rate K was 0.86. The total, natural, and fishing mortalities were estimated at 2.46, 1.71, and 0.75 y^{-1}, respectively. The size at first sexual maturity was 8.9 and 9.2 cm, respectively, for males andfemales. The size at first capture was estimated at 9.2 cm, which indicates that fish spawn at least once before capture. The current exploitation rate of 0.31 remains below the maximum exploitation rate E_{max} which was 0.604 but was equal to the exploitation rate retaining 50% of the biomass of the stock ($E_{0.5}=0.324$). This suggests that the stock of *S. m. melanotheron* is not overexploited in the complex. However, it is recommended that the actual rate of exploitation be kept as it is to ensure a sustainable management of these fish populations.

Keywords: Cichlid / ELEFAN / Lagoon fisheries / Ouémé river / Demographic parameters

1 Introduction

In Benin, several studies meant to update data on fish fauna inventory and its exploitation have been carried out in recent years (Lalèyè, 1995; Lalèyè et al., 2003, 2004; Moritz et al., 2006; Montchowui et al., 2007; Moritz, 2010; Ahouansou Montcho, 2011; Lederoun et al., 2015, 2016, 2018a,b; Adjibade et al., 2019; Imorou et al., 2019; Moritz and Lalèyè, 2019) but those studies have mostly focused on large river basins, leaving lakes and lagoons often heavily exploited by the local population (Lederoun et al., 2015, 2016). In southern Benin, there are some lakes and lagoons along the coastline: Lake Ahémé, the Coastal lagoon, the old lagoons (Toho, Todougba, Dati, Ahoungan, and Djonou), and the Lake Nokoué and Porto-Novo Lagoon complex. This lagoon complex remains the most important waterbody from the point of view of its extent, productivity, and exploitation (Lalèyè, 2000). Overall, this latter component, i.e., exploitation, has been very little-documented in recent years despite fishing pressure on the target species (Lalèyè, 2000). Indeed, the latest available information on the exploitation of the complex's resources is that of Niyonkuru (2007) on Lake Nokoué, highlighting the heavy massive exploitation of three cichlids (*Sarotherodon melanotheron*, *Coptodon guineensis,* and *Hemichromis fasciatus*). Since then, changes have been noted in this ecosystem and especially in the entire lagoon system. In fact, over the past decade, the aquatic space of the complex has been taken over by man for various uses. This was mainly because of anarchic occupation of the two bodies of water by the fishermen for the establishment of sedentary fisheries through acadjas (a type of fish parks composed either of branches stuck in the bottom of water or of floating vegetation), thus reducing the aquatic space available for other fishing practices (Vodougnon et al., 2018).

Available national data of 1998 show that inland fishing produces 33,000 tonnes y^{-1}, 6,000 tonnes of which come from the acadjas (Aglinglo, 1998). Most of these catches are provided by brackish water bodies (95% of the total, i.e., 31,000 tonnes). Lake Nokoué alone accounts for more than

*Corresponding author: ldjiman@yahoo.fr

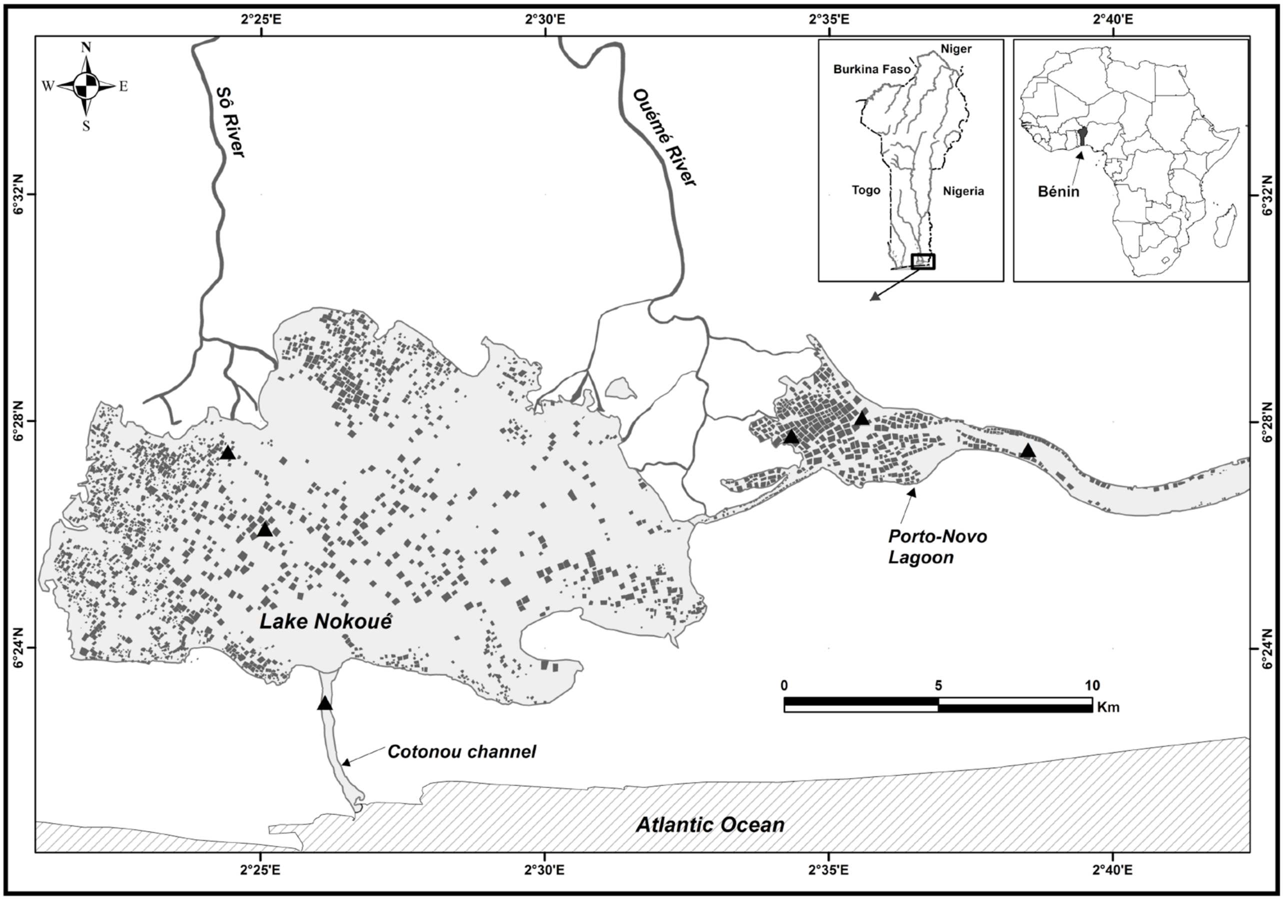

Fig. 1. Study area, showing sampling sites (▲) and acadjas (■).

69% of the total production (22,000 tonnes). According to statistics from the Fisheries Production Department, the production of Lake Nokoué increased from 1993 to 1996, going from 18,000 tonnes to 21,900 tonnes. This increase is mainly due to the rise in the number of acadjas, which went from 589 (covering 311.8 ha) in 1981 to 9,078 (5,931 ha) in 1996 (Aglinglo, 1998). Even if updated statistics do not currently exist, the number of acadjas and space occupied by these sedentary fisheries has increased considerably in recent years, impacting the number of fishermen. We have gone from nearly 17,000 fishermen in 1990s–96 to 11,492 from 1997. The decrease in the number of fishermen from almost 17,000 in 1990s–96 to 11,492 in 1997 in favor of other activities is a sign of reduced yield despite increased fishing effort. However, in addition to this very controversial method of exploitation, there is also the use of devastating fishing gear and techniques in the few open spaces, such as small mesh nets, which are often reported in the complex. Faced with all these disturbances and threats mentioned on these fish species, there is an urgent need to update data on the most exploited fish species' population dynamics in the Lake Nokoué and Porto-Novo Lagoon complex. Among these most exploited species are the Cichlidae, *Sarotherodon melanotheron melanotheron*. Indeed, statistical surveys (Lalèyè et al., 2003; Niyonkuru, 2007) have shown that *S. m. melanotheron* is most abundant in Lake Nokoué with *Coptodon guineensis* (Cichlidae) and *Ethmalosa fimbriata* (Clupeidae). Overall, *S. m. melanotheron* represents 72% of the total catches of fish of the Cichlidae family in Lake Nokoué outside the acadjas and nearly 87% in the acadjas (Niyonkuru, 2007). A recent study on the exploitation of the species in Lake Toho in Benin (Lederoun et al., 2015) showed that *S. m. melanotheron* has reached high levels of exploitation due to increasing demand in recent years, and its economic value. In the Lake Nokoué and Porto-Novo Lagoon complex, where the species is also abundant, up-to-date information on demographic parameters is lacking, which significantly limits decision-making in terms of the management of renewable resources exploited.

This is the context within which this study is conducted, aiming to assess the population dynamics and exploitation of *Sarotherodon melanotheron melanotheron*, one of the main species caught by fishermen in the Lake Nokoué and Porto-Novo Lagoon complex.

2 Materials and methods

2.1 Study area

The fish were caught in Lake Nokoué (6°20′ to 6°30′N and 2°20′ to 2°35′E) and the Porto-Novo Lagoon (6°25′ to 6°30′N and 2°30′ to 2°38′E) in Benin (Fig. 1). Lake Nokoué, which connects to the Porto-Novo Lagoon through the Totchè canal, covers an area of about 150 km^2 and is freshwater-fed by both the Ouémé and Sô Rivers (Niyonkuru and Lalèyè, 2010;

Vodougnon et al., 2018). It is also affected by the Cotonou tidal channel through which seawater reaches it (Lalèyè, 1995; Lalèyè et al., 2003; Vodougnon et al., 2018). Less stretched than the Nokoué Lake, the Porto-Novo Lagoon covers 35 km^2 (Lalèyè, 1995; Gnohossou, 2006). It is the point through which the Ouémé River's waters reach the ocean through the Lagos tidal channel. Lake Nokoué and Porto-Novo Lagoon complex are subject to a sub-equatorial climate characterized by an alternation of two rainy seasons (early April through mid-July and mid-September through mid-November) and two dry seasons (mid-November through late March and mid-July through mid-September) due to its geographical location (Vodougnon et al., 2018).

2.2 Sampling methods

Between January and December 2015, fish samples (N = 1,745) were collected randomly from artisanal fishermen who operated scoop nets, monofilament gillnets, casts nets, and acadjas at six sampling sites (Fig. 1). They were transported to the laboratory for identification using the key by Teugels and Thys van den Audenaerde (2003). Each specimen was measured for total length to the nearest 0.1 cm using measuring-tape, individually weighed (fresh weight) to the nearest 0.01 g using an electronic precision balance, and sexed (immature, male, or female) following the criteria of Brown-Peterson et al. (2011). Some of the fish were deposited in the Royal Museum for Central Africa (RMCA), Tervuren, Belgium, to establish a reference collection.

2.3 Data processing

The relationship between total length and the total weight was established using the equation:

$$BW = aTL^b (\text{Le Cren, 1951}) \quad (1)$$

where BW is wet body weight (g), TL total length (cm), a the intercept, and b the slope of the linear regression. The 95% confidence limits for b were assessed using Statview software, version 1992–98 (SAS Institute INC). In order to check whether b is significantly different from 3, the Student t-test was conducted following Sokal and Rohlf (1987):

$$ts = \frac{(b-3)}{\text{SE}} \quad (2)$$

where ts is the t-test value, b the slope, and SE the standard error of b.

Size at first maturity (L_{50}) was estimated for both sexes using a logistic function that was fitted to the proportion of sexually mature individuals by each size class using a non-linear regression following King's (1995) formula:

$$P = 1/\{1 + \exp[-r(L - Lm)]\}, \quad (3)$$

where P is the proportion mature in each size class, r ($-b$ slope) is a parameter controlling the slope of the curve, and Lm is the size at which 50% of fish are mature (Saila et al., 1988). Statistical analyses and plots were generated using R (R Development Core Team, 2018) with sizeMat (Torrejon-Magallanes, 2019) package. Likelihood-ratio tests were performed to detect differences in L_{50} values between sexes.

For the growth analysis, the length-frequency data were pooled into groups with 1 cm length class intervals. The growth parameters such as asymptotic length ($L\infty$) and growth rate (K) were obtained using Von Bertalanffy Growth Function (VBGF). The ELEFAN I (electronic length-frequency analysis) software tool included in FiSAT II (FAO ICLARM Stock Assessment Tools) (Gayanilo et al., 1996) was used to estimate the parameters $L\infty$ and K of the von Bertalanffy equation. According to VBGF, individual fishes grow on average towards the asymptotic length at an instantaneous growth rate (K) with length on time (t) following the expression:

$$TL = L\infty\left(1 - e^{-K(t-t0)}\right) \quad (4)$$

where TL is the total length of the fish at time t, $L\infty$ is the asymptotic length of fish (cm), K is the rate at which TL approaches $L\infty$, and t_0 is the theoretical age of the fish when TL is equal to zero.

The theoretical age at length zero (t_o) was estimated by the equation of Pauly (1979):

$$\log_{10}(-t_0) = -0.392 - 0.275\log_{10}L\infty - 1.038\log_{10}K \quad (5)$$

The longevity, $t$max, was calculated using the following formula (Taylor, 1962; Pauly, 1980):

$$t\text{max} \approx \frac{3}{K} \quad (6)$$

The growth performance index (phi prime, Φ') was estimated using the equation of Pauly and Munro (1984):

$$\varphi' = \log_{10}K + 2\log_{10}L\infty \quad (7)$$

The total mortality coefficient Z (y^{-1}) was estimated by a length-converted catch curve (Pauly, 1984).

The natural mortality rate M (y^{-1}) which caused by all other factors except fishing, was estimated according to Pauly's (1980) empirical formula:

$$\text{Log}_{10}M = 0.654\log_{10}K - 0.28\log_{10}L\infty + \log_{10}T \times 0.4634 - 0.0066 \quad (8)$$

where K and $L\infty$ are the parameters of the equation (4) and T the average annual temperature of the water which is 28 °C. The Fishing mortality rate (F) was estimated using the relation:

$$F = Z - M \quad (9)$$

The exploitation rate (E) was calculated by the quotient between fishing and total mortality (Pauly, 1984):

$$E = F/Z \quad (10)$$

The length at which 50% of the fishes are selected by the gear (Lc = size at first capture) was estimated using the ogive selection (Pauly, 1984).

The optimal length Lopt was estimated using Froese's (2004) equation:

$$L\text{opt} = L\infty(3/(3 + (M/K))) \quad (11)$$

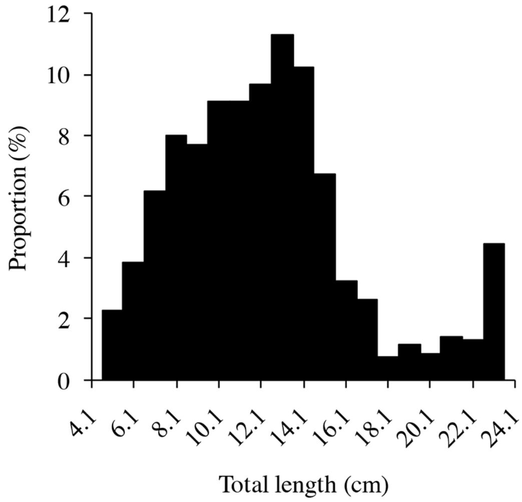

Fig. 2. Size frequencies for *Sarotherodon melanotheron melanotheron* (Cichlidae) in Lake Nokoué and Porto-Novo Lagoon complex (N= 1,745).

where $L\infty$ and K are function of the von Bertalanffy growth and M the natural mortality rate.

Relative yield per recruit (Y'/R) was estimated using Beverton and Holt's (1966) model as follows:

$$Y'/R = EU^{M/K}\left[\frac{1-(3U)}{(1+m)}+\frac{(3U^2)}{(1+2m)}-\frac{(U^3)}{(1+3m)}\right] \quad (12)$$

where $E=F/Z$ corresponds to the current exploitation rate, i.e. the fraction of the total mortality caused by fishing activities. $U=1-(Lc/L\infty)$ = the fraction of growth to be completed by the fish after its entry into the exploitation phase (Lc = mean length at first capture, $L\infty$ = asymptotic length), $m=(1-E)/(M/K)=K/Z$. The Relative Y'/R analysis assumed that the fish species conforms to knife-edge recruitment and knife-edge selection. The relative biomass per recruit (B'/R) was estimated as:

$$B'/R = \frac{(Y'/R)}{F} \quad (13)$$

The recruitment patterns were computed following the method described in the FiSAT routine (Gayalino et al., 1996).

3 Results

3.1 Size frequencies and length-weight relationship

For 1,745 *S. m. melanotheron* samples collected between January and December 2015, the total length ranged from 4.6 to 23.1 cm, with an average of 11.6 ± 3.3 cm (Fig. 2). The weight of caught fishes varied between 2.76 and 286.43 g with an average of 36.44 ± 30.25 g. The length-weight relationships was described by the equation $W=0.036\ TL^{2.742}$; ($r^2=0.963$; SE = 0.137) with a strong correlation (see r^2) linked here to the wide size range of sampled fish (Fig. 2), the difference between the extreme length values being 18.5 cm. The allometric coefficient b was significantly lower than 3 ($ts=-1.88$; confidence interval at 95% for b: 2.715–2.769), so growth was a negative allometric growth.

3.2 Size at first maturity

The logistic fit method suggests 50% of female *S. m. melanotheron* in the Lake Nokoué and Porto-Novo Lagoon complex are sexually mature at 9.2 cm TL with 95% confidence intervals ranging from 9.1 to 9.4 cm TL (Fig. 3). For males, corresponding values are 8.9 cm TL et 8.5–9.2 cm TL for size at first maturity and confidence intervals, respectively (Fig. 3). There was no significant difference in the estimated size at maturity between males and females ($p=0.754$).

3.3 Growth parameters

The asymptotic length $L\infty$ and the growth coefficient K were 24.68 cm and 0.86 y^{-1}, respectively. The growth performance index ϕ' was relatively high for this species, estimated at 2.42, and the theoretical ages at which length is 0 was estimated at −0.2 year. The potential longevity $t$max was 3.49 years. Specimens of *S. m. melanotheron* captured during the study period belonged to 4 cohorts (Fig. 4).

3.4 Mortality and exploitation rate

The total mortality (Z) estimate from the length converted catch curve was 2.46 y^{-1} (Supplemental Fig. S1). The natural mortality rate (M) and fishing mortality rate (F) were 1.71 y^{-1} and 0.75 y^{-1}, respectively. The current exploitation rate was estimated as $E=0.31$.

3.5 Size at first capture and optimal size

The length at first capture (Lc), i.e., the length at which 50% of the *S. m. melanotheron* species are vulnerable to capture, was estimated at 9.2 cm (Fig. 5). The logistics model selection also showed that 25% of fish at 6.6 cm and 75% of fish at 11.9 cm were caught. All fish over 23.5 cm were systematically caught. The estimated optimal length was 14.8 cm.

3.6 Relative yield per recruitY'/R and reference points

In the Lake Nokoué and Porto-Novo Lagoon complex, the relative yield curves per recruit Y'/R relative to the exploitation ratio E, indicated an optimal exploitation rate (Emax) of 0.610 (Fig. 6). The exploitation rate $E_{0.1}$ (exploitation rate at which the marginal increase of Y'/R is 10% of its entire stock) and $E_{0.5}$ (exploitation rate under which the whole stock is halved) were respectively estimated at 0.515 and 0.325.

3.7 Recruitment patterns

Recruitment patterns of *S. m. melanotheron* from the Lake Nokoué and Porto-Novo Lagoon suggested that recruitment was continuous throughout the year with two distinct spawning events (minor and major) (Fig. 7). The minor peak of

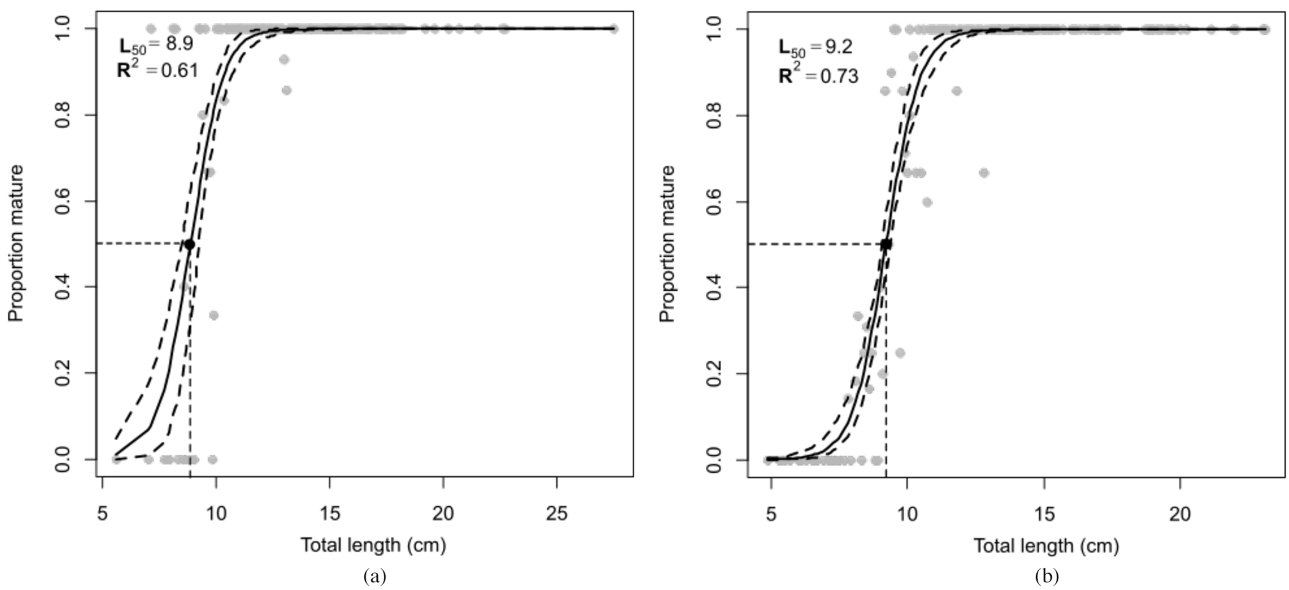

Fig. 3. Estimated size at first maturity for males (a) and females (b) of *Sarotherodon melanotheron melanotheron* from Lake Nokoué and Porto-Novo Lagoon complex.

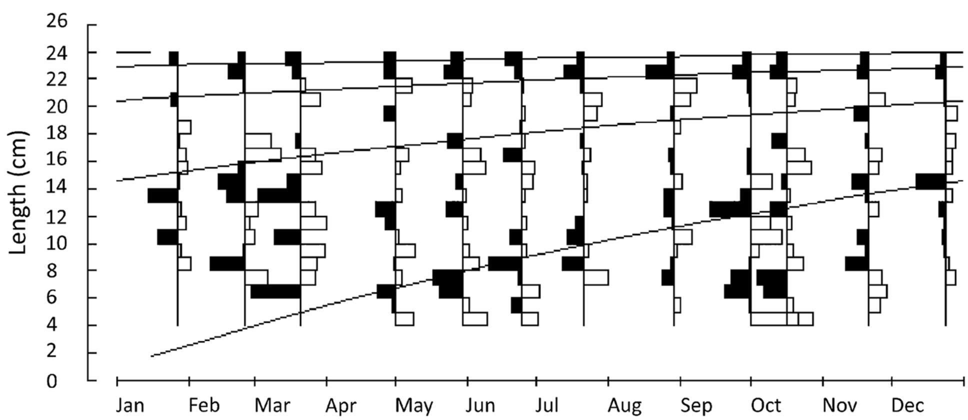

Fig. 4. Length frequency data superimposed on the growth curve (Continuous line) of *Sarotherodon melanotheron melanotheron* from Lake Nokoué and Porto-Novo Lagoon complex ($L\infty = 24.68$ cm total length, $K = 0.86\ y^{-1}$). The bars represent the restructured length frequency data, where black bars indicate positive peaks and white bars represent negative peaks.

recruitment occurred in March-April with a recruitment strength of 12.60% and 12.61%, respectively, whereas the significant rise occurred in August with a recruitment strength of 18.96%.

4 Discussion

Length-weight relationships play a significant role in assessing the biology of fish fauna (Abowei et al., 2009; Akintola et al., 2010). The relationships between length and weight (with coefficient $b = 2.742$) for 1,745 specimens of *S. m. melanotheron* indicates a negative allometric growth. Which means that, the increase in length was faster than the growth in weight in this study. This result is consistent with that of Lederoun et al. (2015), who reported negative allometric growth ($b = 2.9593$) for this species in Lake Toho in Benin. The same kind of growth ($b = 2.812$) has also been reported for the same species in the Ayamé I reservoir in Ivory Coast (Tah et al., 2012) and from the coastal rivers ($b = 2.815$) of the south-eastern part of Ivory Coast (Konan et al., 2007).

The size of 8.9 and 9.2 cm TL first sexual maturity obtained respectively for males and females is more significant than that reported by Lederoun et al. (2015) for the same species in Lake Toho, i.e., 6.9 and 7.7 cm TL for males and females, respectively. Apart from the fishing pressure reported in Lake Toho by Lederoun et al. (2015), the presence in number and on large surfaces of acadjas in Lake Nokoué (1933 acadjas, 22.13 km^2) and Porto-Novo Lagoon (474 acadjas, 7.93 km^2) (see Fig. 1) complex could explain this size difference. Indeed, acadja is a vast artificial fish aggregation device made up of clumps of branches implanted in shallow areas of a water body.

The installation generally allows the fish to shelter from predators and feed on the microorganisms that colonize this environment, which would increase the size of the fish and catch per unit area compared to open water fishing. The hiding places constituted by the acadjas would also help reduce the fishing pressure on the fish before their exploitation, which generally takes place at least one year after their installation. It is a traditional fishing practice that is profitable if well managed (Welcomme, 1972; Lalèyè, 2000). The size at first maturity for *S. m. melanotheron* in the complex remains lower than that obtained in Lake Doukon (12.8 and 13.2 cm for males and females, respectively) and Lake Togbadji (12.4 and 11.5 for males and females, respectively) for *Sarotherodon galilaeus galilaeus* (Lederoun et al., 2016). The reduction in size at first sexual maturity as a function of fishing pressure is well known among cichlids (Leonardis and Sinis, 1998; Panfili et al., 2004; Lederoun et al., 2015).

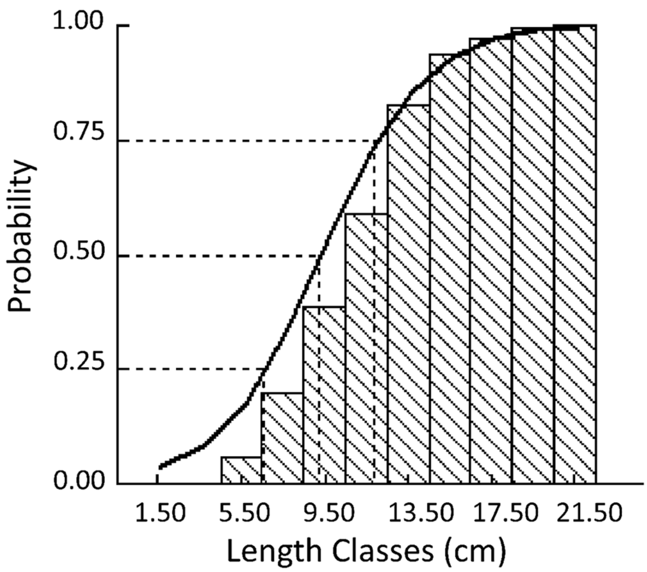

Fig. 5. Probability of capture of *Sarotherodon melanotheron melanotheron* from Lake Nokoué and Porto-Novo Lagoon complex estimated from the ascending axis of the catch curve.

According to Alhassan and Armah (2011), estimation of growth and mortality is fundamental in fisheries because stock assessment and management rely on these population parameters. There are several mathematical models for expressing change. Von Bertalanffy's model remains the most used (Hilborn and Walters, 1992). The von Bertalanffy model's growth parameters are often obtained using size frequency distributions, especially for tropical fish, to circumvent the difficulties linked to the interpretation of growth marks on hard parts (otolithometry, e.g.). In the present study, this model has been used to estimate growth parameters and those of mortalities. The model has the advantage of accurately describing the growth in the interval of the observed data, and it is easily incorporated into production models (Gaamour, 1999; Rjeibi et al., 2011). In principle, statistical software MIX (MacDonald and Pitcher, 1979), MULTIFAN (Tuck et al., 1997), and ELEFAN are excellent examples (Wahle and Fogarty, 2006). Still, in this study, ELEFAN, designated by ELEFAN I in the FiSAT II fisheries analysis software, was chosen. ELEFAN allows an estimation of growth parameters by a direct projection of frequency-size data without first translating the length scale into an age scale (Gayanilo et al., 2005). ELEFAN has been widely used in previous studies on Lake Nokoué (Villanueva, 2004; Niyonkuru, 2007; Niyonkuru et al., 2007) and elsewhere (King and Etim, 2004; Montchowui et al., 2009; Montchowui et al., 2011; Lederoun et al., 2015, 2016) and therefore remains the most appropriate in cases of growth comparison between populations and species.

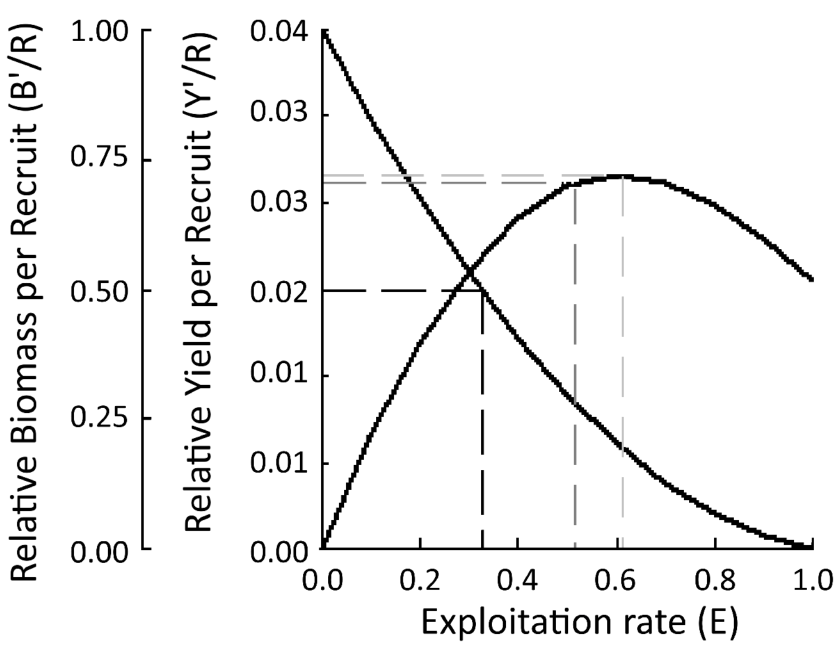

Fig. 6. Relative yield-per-recruit and biomass-per-recruit curves for *Sarotherodon melanotheron melanotheron* from Lake Nokoué and Porto-Novo Lagoon complex using the selection ogive option. The three dashed right-angled lines correspond to *E*0.5, *E*0.1 and *E*max, respectively.

In this study, the growth coefficient K was estimated at 0.86 y^{-1}; the asymptotic length $L\infty$ obtained was 24.68. Referring to the criteria for determining the modes of growth of Branstetter (1987) who estimated that in a given species, growth is slow when $0.05 < K < 0.10$ y^{-1}, intermediate when $0.10 < K < 0.20$ y^{-1}, rapid when $0.20 < K < 0.50$ y^{-1}, and very rapid when $K \geq 0.5$, *S. m. melanotheron* has a very rapid growth in the Lake Nokoué and Porto-Novo Lagoon complex, which agrees with the good primary productivity of the complex (Sarmento et al., 2009). The four generations identified in the complex are lower than the six generations identified in Lake Toho (Lederoun et al., 2015) for the same species. Different environmental conditions could explain this situation. The relatively high fishing pressure in Lake Toho would favor rapid multiplication to the disadvantage of growth.

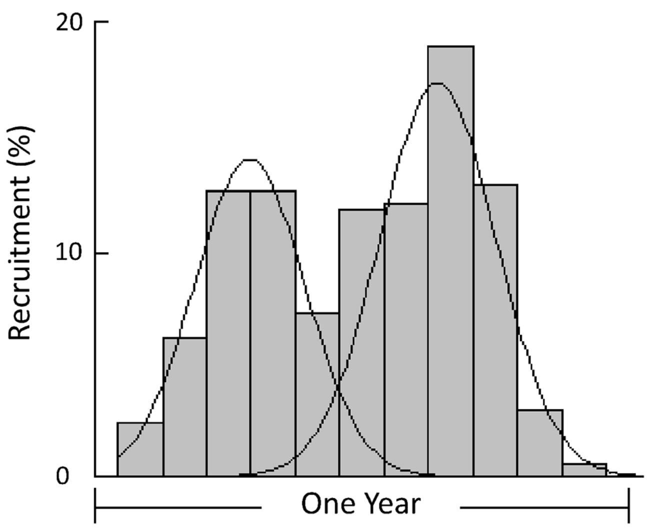

Fig. 7. Recruitment pattern of *Sarotherodon melanotheron melanotheron* from Lake Nokoué and Porto-Novo Lagoon complex showing two recruitment peaks per year.

The estimated growth performance index ($\varphi' = 2.42$) is similar to those found in the literature (Tab. 1). The slight variations observed would be due to the availability of food, to population density (Lederoun et al., 2015, 2016; Bédia et al., 2017), differences in accessibility to food (Pauly, 1994), differences in ecosystem temperatures (King and Etim, 2004), environmental pollution, fisheries degradation (Abowei and Hart, 2007, 2009) and fishing pressure (Lederoun et al., 2015).

March-April and August periods are those of great recruitments for *S. m. melanotheron* in the study site. This coincides with the periods of greatest recruitments of *S. m. melanotheron* in Lake Ahémé (Niyonkuru, 2007) and Lake Toho (Lederoun et al., 2015), and from *Sarotherodon galilaeus galilaeus* in Lake Doukon and Lake Togbadji (Lederoun et al., 2016). Our observations are consistent with those of Pauly (1980), who found that tropical fish species mostly exhibit double recruitment pulses. The two peaks of recruitment are observed during the rainy period and, particularly, during the period of flooding of the plains in August-September in southern Benin. This suggests that an abundance of food during the rainy seasons favors juveniles' recruitment into the population. The high proportions of individuals in the advanced gonad maturation stages (stages 3 and 4) were observed during these periods that Koné (2000) considers as the periods during which trophic conditions become favorable for young fish's growth.

The decrease in the size of a population can be attributed to two causes: natural death (M) (disease, predation, etc.) and fishing pressure (F). For this work, the mortality study was based on concepts defined by Beverton and Holt (1957) and Gulland (1963). Once the value of M was determined, the M/K ratio is often used to examine the accuracy of growth

Table 1. Growth parameters ($L\infty$ = Asymptotic length, to = Theoretical age at length zero, $t$max = Longevity, Φ' = Growth performance index, and K = Growth coefficient), mortality estimates (Z = Total mortality, M = Natural mortality, and F = Fishing mortality), and exploitation rates (E) from different fishing areas in West Africa, including the estimates of the present study.

Country	Locality	$L\infty$ (cm)	K (y^{-1})	t_o (y)	$t$max (y)	Φ'	M (y^{-1})	M/K	Z (y^{-1})	F (y^{-1})	E (y^{-1})	References
Nigeria	Lagos lagoon	33.1	0.159	–	–	2.24	–	–	–	–	–	Fagade (1974)
Senegal	Sine-Saloum estuary	22	0.6	–	–	–	1.081	–	–	1.135	–	Villanueva (2004)
Ivory Cosat	Ebrié Lagoon	34	0.42	–	–	–	0.976	–	–	0.224	–	Villanueva (2004)
Gambia	Gambia estuary	37	0.39	–	–	–	0.893	–	–	0.847	–	Villanueva (2004)
Benin	Lake Nokoué (outside acadjas)	24.1	0.55	0.5	5.5	2.5	1.28	2.33	1.66	0.38	0.23	Niyonkuru (2007)
Benin	Lake Nokoué (in acadjas)	26.7	0.79	0.68	3.8	2.75	1.58	2	2.41	0.83	0.34	Niyonkuru (2007)
Benin	Lake Ahémé	22.5	0.52	-0.46	5.7	2.42	1.26	2.42	2.1	0.85	0.4	Niyonkuru (2007)
Benin	Lake Nokoué	27	0.8	-0.21	3.8	2.73	1.5	1.87	2.3	0.7	0.32	Niyonkuru et al. (2007)
Ivory Cosat	Lake Ayamé I	31	0.39	–	–	2.57	–	–	–	–	–	Tah et al. (2010)
Benin	Lake Toho	21.53	0.58	-0.31	5.17	2.43	1.37	2.36	1.95	0.58	0.3	Lederoun et al. (2015)
Benin	Lake Nokoué and Porto-Novo Lagoon	24.68	0.86	-0.2	3.49	2.42	1.71	1.98	2.46	0.75	0.31	Present study

parameters (Chakraborty, 2001) and for a rapid diagnosis of fisheries (Pauly and Moreau, 1997). In the first case, it is supposed to be constant for a group of species or closely related families or taxa (Chakraborty, 2001). It should generally fall within the range of 1.12–2.5 (Beverton and Holt, 1959). In the second case, it is strictly greater than 2 for populations with a low longevity (Pauly and Moreau, 1997). The M/K ratio of 1.98 obtained in this study reflects the reliability of M and K, an excellent environmental state (Beverton and Holt, 1959), and a long-lived population (Pauly and Moreau, 1997). The M/K ratio of Lake Nokoué and the Porto-Novo Lagoon is similar to those obtained in Lake Doukon (2.06) and Lake Togbadji (1.99) for *S. g. galilaeus* (Lederoun et al., 2016) and in Lake Toho (2.36) for *S. m. melanotheron* (Lederoun et al., 2016).

In the studied species, the Z/K ratio was 2.86, expressing a predominance of mortality overgrowth, on the one hand, and a slight exploitation, on the other hand (Barry and Tegner, 1989). King and Etim (2004) have also reported that Z/K ratio of less than or approximately close to 2 indicates that the targeted species' population is lightly exploited for a mortality-dominated community. Besides, natural mortality was higher than fishing mortality. Therefore, demography is strongly influenced by natural mortality linked to predation, disease, or other causes not related to fishing. This higher natural mortality is associated with a higher growth coefficient (K). Chauvet (1988) then Pauly and Yañez-Arancibia (1994) indicated that lagoons' ecological conditions seem to have a positive influence on growth but not on the mortality coefficient.

The high values of M and K indicate that these fish have high biomass turnover rates. According to Sparre and Venema (1992), the high growth coefficients, the short asymptotic lengths, and the high natural mortality indicate that the fish matures early and has a short lifespan. According to these same authors, if the natural mortality rate M is high, the fish quickly reaches the age or the loss due to natural mortality exceeds the gain in biomass due to growth. Fishing mortality should be higher to catch fish before they die from natural causes. Fish populations are considered to be below optimal exploitation when fishing mortality is lower than natural mortality. High values of natural mortality ($Z = 2.3$ and $M = 1.5$) were observed by Niyonkuru et al. (2007) in Lake Nokoué and by Lederoun et al. (2015) in Lake Toho ($Z = 1.95$ and $M = 1.37$). Even if the use of landing nets was mentioned in Lake Toho, the high proportion of predators (See Vodougnon et al., 2018) in Lake Nokoué and the Porto-Novo Lagoon is mostly responsible for the high value of natural mortality recorded. The low fishing mortality observed is partly linked to the fact that the catch also involves other species enjoyed by the community and abundant in catches such as *Coptodon guineensis*, *Chrysichthys nigrodigitatus*, *Ethmalosa fimbriata*, *Pellonula leonensis*, *Neochelon falcipinnis*.

The size of the first catch (Lc) is, by definition, the size at which the catching gear selects 50% of the fish. Thus, it is estimated that fish within this size is in the unexploited phase, and, from this, they suddenly become exposed to full exploitation. In this study, the size at first capture ($Lc = 9.2$ cm) is greater than or equal to the size at first maturity (8.9 and 9.2 cm TL, respectively for males and females), supporting the earlier assertion that the stock of *S. m. melanotheron* in the Lake Nokoué and Porto-Novo Lagoon complex are not overexploited. In the studied site, about 79.7% of the caught fishes (Fig. 2) are >9.2 cm TL (L_{50} of females), which means that many individuals of *S. m. melanotheron* are captured after reaching the matured stage and adding to the biomass of the population.

Two assumptions and data are used to calculate the yield and the relative biomass per recruit: (1) the selection of type "knife-edge," which excludes that fish of sizes lower than Lc are not caught by the gear and (2) the "ogive selection" which assumes that the probability of catching any fish depends on its length. This size is then obtained from the selectivity curve of the net (Sparre et al., 1989). From this size the fish become vulnerable to nets. In this study, we have used the second method because it seems logical that the probability of the fish being caught by a given gear depends on its size.

As far as the level of exploitation is concerned, the current exploitation rate estimated approximately at 0.31 was substantially equal to the optimal rate of 0.325 obtained with the relative yield curve per recruit Y'/R. This result highlighted that the *S. m. melanotheron* population is currently at an optimum level of exploitation (Beverton and Holt, 1957; Lederoun et al., 2016). This situation is similar to the one mentioned on Lake Nokoué by Niyonkuru et al. (2007) but is contrary to what one observed in Lake Toho where species is strongly overexploited (Lederoun et al., 2015). The use of acadjas might explain the reasonable current exploitation rate recorded in this complex. But as reported by Lederoun et al. (2016) for Lake Doukon and Lake Togbadji, the rational exploitation of species could easily switch to overexploitation in the future if sensitization sessions advocating sustainable fishing methods are not organized. The government currently commissions a new study on reorganizing the acadjas in the complex and removing prohibited gear, which reassures the fishing pressure in the future. In southern Benin, fish is the primary protein source, and this complex is the leading supplier.

5 Conclusion

The lengths of first capture and first sexual maturity observed during this study, the Z/K ratio, and the current exploitation rate are indicators of rational exploitation of *S. m. melanotheron* in the Lake Nokoué and Porto-Novo Lagoon complex. Compared to the known situation in most lakes in southern Benin in which the species are overexploited, it seems here that the number of acadjas and the area they occupy considerably limit the overfishing of the species. This could be explained since the exploitation generally takes place at least a year after the installation of the branches, allowing the fish to reach the size of maturity and contribute to the exploitable biomass. However, the reorganization of these sedentary fisheries is still essential to avoid conflicts between fishermen. We also recommend reducing the fishing effort from March to April and August, when juvenile fishes' recruitment is very intense.

Supplementary Material

Fig. S1. Length-converted catch curve for *Sarotherodon melanotheron melanotheron* from Lake Nokoué and

Porto-Novo Lagoon complex. Solid dots are those used in calculating the parameters of the straight line, the slope of which (with sign changed) is an estimate of Z. Open dots represent fish not fully selected by the gear used in the fishery, and grey dots are those not used in mortality estimation.

The Supplementary Material is available at https://www.alr-journal.org/10.1051/alr/2020018/olm.

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