E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2019; 7(6): 94-103

www.fisheriesjournal.com
Received: 07-09-2019
Accepted: 09-10-2019

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Size structure, fecundity and reproductive period of *Malapterurus electricus* (Gmelin, 1789) (Siluriformes: Malapteruridae) in the dam lake of Buyo (Côte d'Ivoire)

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Abstract
The present study determined the morphometric characteristics, fecundity and reproductive period of *Malapterurus electricus*, species of ecological and economic interest in order to assess its aquaculture potential and contribute to its conservation due to the fishing pressure. A total of 325 specimens were monthly sampled from August 2017 to July 2018. 188 males (average body weight 134. 89 ± 82.90 g and average height (SL) 17.02 ± 3.32 cm) and 137 females (average weight 140. 84 ±7 6.23 g and average height (SL) 17.18 ± 3.26 cm) were examined. The distribution of the size frequency showed an unimodal structure of modal class 16 to 18 cm. The length-weight relationship showed that whatever the sex, *Malapterurus electricus* presents a minor allometry. The overall sex ratio (F/M) (1: 1.37; $\chi^2 = 1.71$; *p-value* > 0.05) is in favour of males. The first sexual maturity sizes of 15.27 cm and 15.90 cm (SL) were determined for females and males, respectively. The estimated mean condition factor (Kc) is 2.53 ± 0.34 for females and 2.46 22 ± 0.39 for males. The breeding season of *Malapterurus electricus* runs from April to November. The absolute fecundity determined, ranges from 1016 to 3761 oocytes with an average value of 1813 24 ± 895 oocytes.

Keywords: Absolute fecundity, frequency of size, *Malapterurus electricus*, size of first maturity

Introduction
Fish is a main natural resource providing animal protein for African populations (Micha and Franck, 2004) [1]. In Côte d'Ivoire, demand for fish-derived animal protein remains strong and sustained with current fish consumption ranging from 11 to 14 kg/Hab/year (FIRCA, 2013) [2]. In this context, changes are being observed in the way fisheries are exploited. Increasingly, there is a commercial fishery on the water at the expense of subsistence fishing (Njiru *et al*., 2005) [3] with the advent of colossal means and more efficient catch techniques. Unfortunately, such methods of harvesting aquatic fauna have a negative impact on the fishery resource. These include a decrease in species abundance and fishing yields, a reduction in the maturity size of landed individuals, and a change in the population structure of species for the benefit of less prized species (Garcia *et al*., 1986; Boussou *et al*., 2005) [4, 5].
Lake Buyo remains one of Côte d'Ivoire's major hydro-electric dam lakes, home to intense fishing activities (Da Costa and Dietoa, 2007) [6]. Among the fish species landed on this lake, *Malapterurus electricus* is one of the main exploited species (Goli Bi *et al*., 2019 a) [7]. Highly valued by local residents, *M electricus* is being overexploited in the Buyo Dam Lake (Goli Bi *et al*., 2019 b) [8]. According to these authors, the stock level predictions of *M. electricus* (E = 0.46; $E_{0.5}$ = 0.33) indicate that 50% of its untapped biomass would already be reduced. Such fisheries indicators require that vigorous measures be taken for the rational exploitation of *M. electricus* stock. This requires a real mastery of the ecological and biological traits of the species.
The purpose of this study is therefore to determine the morphometric characteristics, fecundity, condition factor and reproductive period of *Malapterurus electricus* in order to contribute to its conservation.

Materials and methods

Study area

The study was conducted in the Buyo hydro-electric dam lake. This lake is located 120 Km from the mouth near the town of Sassandra and 37 m above sea level. This study area is located between 6°18′ 55N and 6°36′ N, and then between 6°48′ W and 7°12′ W. The hydrological regime of the lake is tropical rainfall (Kouamé *et al*., 2008) [9]. This environment is characterized by four seasons: two dry seasons (December to February and July to September) and two rainy seasons (March to July and September to November) (Kouamé, 2010) [10]. Three sampling stations were selected based on the accessibility and permanence of the water. They are Guessabo, Buyo-ville and PK 15. The Guessabo station is located in the inlet portion of the dam. Buyo-ville is located near the dam dike and the last one (PK 15) is adjacent to the Taï National Park and the N'Zo River (Figure 1).

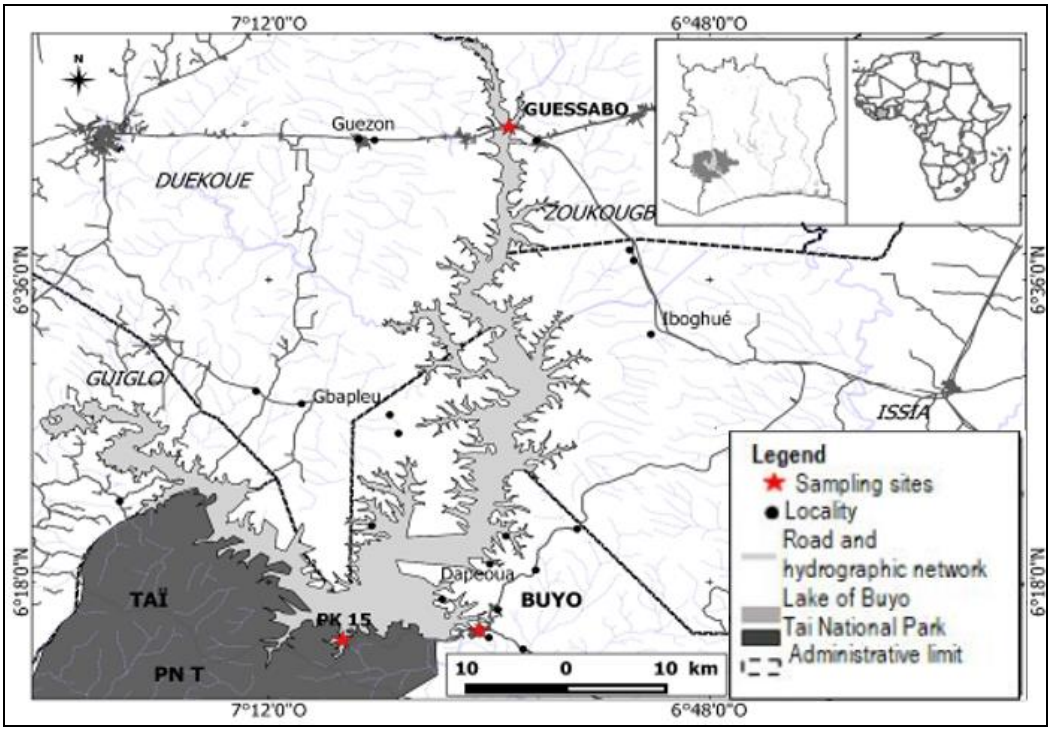

Fig 1: Geographical location of the Dam Lake of Buyo and location of different sampling stations.

Sample Collection, Identification and Measurement

Monthly sampling of specimens of *Malapterurus electricus* was conducted from August 2017 to July 2018. Experimental and commercial fisheries were simultaneously exploited to collect fish. These have been identified according to the Malapteruridae de Paugy and Norris (2003) [11]. At the site, for each specimen, the standard length (SL), total length (TL), total weight and eviscerated weight were recorded to the nearest centimetre for length and to the nearest gram for weight. Gonads and liver were collected and their masses were determined using a digital precision scale of 0.01g accuracy and 300g range.

The size structure in this study was determined on the basis of the Sturge rule by standard 2 cm length class from the collected specimens. The size distribution law of the fish sub-samples was identified and a comparison of sizes between these sub-samples was made using the t-test. Growth is usually materialized by an exponential function. It is represented by the relationship (Le Cren, 1951) [12]: $Pt = aLS^b$ where Pt is the body weight of the fish in grams (g); SL is the standard length of the fish in centimetres (cm); a and b being characteristic parameters of the environment and of the species. The evaluation of the parameters was carried out according to the method of Micha (1973) [13] and Ricker (1980) [14]. In the size-weight relationship, we considered the standard length rather than the total length which undergoes enough modifications. The size-weight relationship was achieved with the Statistica 7.1 software.

Study of the reproduction

Sex-ratio

Sex-ratio (SR) was determined to assess the ratio of males and females according to the following formula:

$$SR = \frac{M}{F}$$

M being the number of male individuals and F being the number of female individuals.

Height of first sexual maturity

To describe the state of rational exploitation, it is essential to determine the size of the first sexual maturity of the species. First sexual maturity size (SL50) was defined as the size at which 50% of the population (males and females) are mature. For this purpose, fish with gonads greater than or equal to 3 were considered to be mature (Ghorbel *et al*., 1996; Légendre and Ecoutin, 1996) [15, 16]. The macroscopic identification scale for *M. electricus'* sexual maturity stages was established according to Fontana (1969) [17] and N'Goran (1995) [18]. This scale has 6 stages of sexual maturity. Stages 1 and 2 are immature. Stages 3 to 6 are mature for both sexes. The non-linear logistic function determining the relationship between the proportion of mature individuals and the standard length of fish was used to determine the size of first sexual maturity (Ghorbel *et al*., 1996) [15]. This sigmoid-shaped function enables the degree of sexual maturity to be monitored by size and the SL50 length to be accurately estimated (Ghorbel *et*

al., 1996) [15] from the following equation:

$P = \frac{1}{1+e^{-(\alpha+\beta LS)}}$ and $SL_{50} = -\frac{\alpha}{\beta}$

P being the proportion of mature individuals, SL is the standard length (cm) and α and β of constants. From this equation, we deduced sizes at SL50.

Evolution of the Gonado-Somatic Ratio and Breeding Period

The description of the reproductive cycle of this species and the determination of the laying period were carried out by regular monitoring of the monthly variations, according to sex and size, of the activity of the genital glands and muscles. These variations were translated into values by the respective ratios: Gonado-Somatic Ratio (GSR) and the condition factor (Kc). The Gonado-Somatic Ratio (RGS) and the condition factor (Kc) were determined according to the following formula: $GSR = \frac{Mg}{Mév} \times 100$ and $Kc = \frac{Mp}{Ls^3} \times 100$ with Mg being the mass of gonads in g, Mev the mass of eviscerated fish in g, Mp the mass of fish in g and SL the standard length of fish in cm. The condition factor was used to determine when the fish became overweight. The monthly evolution of the Gonado-Somatic Ratio (GSR) reflects, in adult individuals, the transition of gonads from one macroscopic stage of maturation to another, marked by changes in size, texture and consistency. For a better determination of the reproductive period, the GSR and the monthly percentage of the advanced stages of sexual maturity were coupled.

Fecundity

The study of the fecundity of *M. electricus* led to the determination of parameters such as: absolute fecundity and relative fecundity. Absolute fecundity is the total number of oocytes carried by a female and relative fecundity is the number of oocytes per unit body weight (Wotton, 1979) [19].

The different mathematical expressions used for the study of fecundity are:

-Absolute fecundity (F)

Fa = N PT/ Pf

With N being the number of oocytes present in the ovary fraction, PT is the total ovary weight (g) and Pf is the weight of the ovary fraction (g).

-Relative fecundity (Fr)

Fr = Fa/ Pev

Where Pep is the weight of the eviscerated fish (g)

Statistical analyses of data

- The khi² test was used to compare the observed sex-ratio values to the theoretical sex-ratio value (1:1).
- The Student t-test was used to compare the allometric coefficients calculated with the threshold allometric coefficient 3.
- The t-test was applied to compare the Kcs and average sizes of the categories of individuals analyzed.
- •These tests were performed using STATISTICA 7.1 software.

Results

Mean values of body parameters

Analysis of the various measurements shows that of the 325 measured individuals of all sexes, the individual weight ranges from 18 g to 540 g. The average total length of the body measured is 20.15 ± 3.84 cm. It varies from 11.5 cm to 34 cm while the standard length is between 10 cm and 28.5 cm with an average of 17. 08 ± 3.29 cm. By separating this sample by sex, the average weight is 134. 89 ± 82.90 g for a medium size (SL) 17.02 ± 3.32 cm in 188 males examined. Among these, the weight ranges from 18 g to 540 g while females, the average weight is 140. 84 ± 76.23 g for a mean size (SL) of 17.18 ± 3.26 cm in 137 individuals studied. In females, the weight ranges from 27 g to 380 g.

The t-test applied to both groups (males and females) shows that there is no significant difference (*T-Value* = -0.660 *P-Value* = 0.509) between the mean weights of the two groups.

Size structure

Of a total of 325 individuals of *Malapterurus electricus* examined, the standard lengths (SL) of the fish measured ranged from 10 to 28.5 cm. Overall, the structure of this population has an unimodal distribution and the samples collected present a greater number of individuals for sizes between 14 and 20 cm (Figure 2). Figure 3 shows that regardless of sex, catches are dominated by individuals between 12 and 22 cm (SL). Females are absent from catches above 28 cm, unlike males that reach nearly 30 cm (LS). The latter are dominant in all the size classes constituted, with the exception of the 18 and 20 cm and 26 and 28 cm size classes.

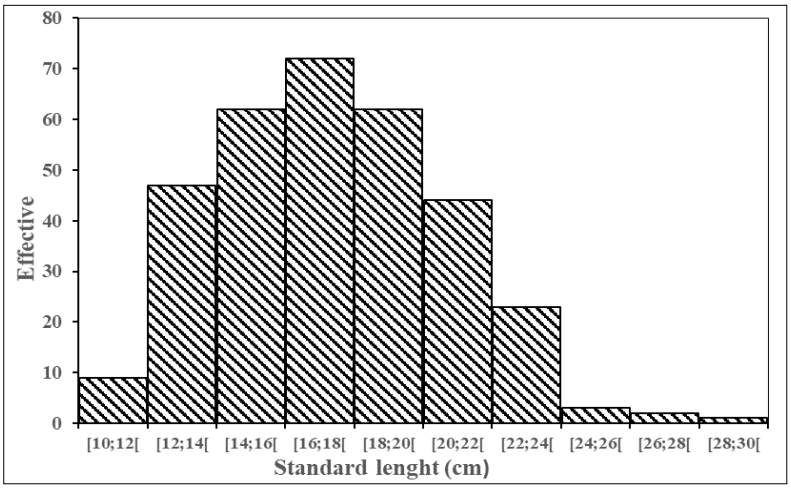

Fig 2: Distribution of all gender sizes of the population of *Malapterurus electricus* captured from August 2017 to July 2018 in the dam lake of Buyo (Côte d'Ivoire).

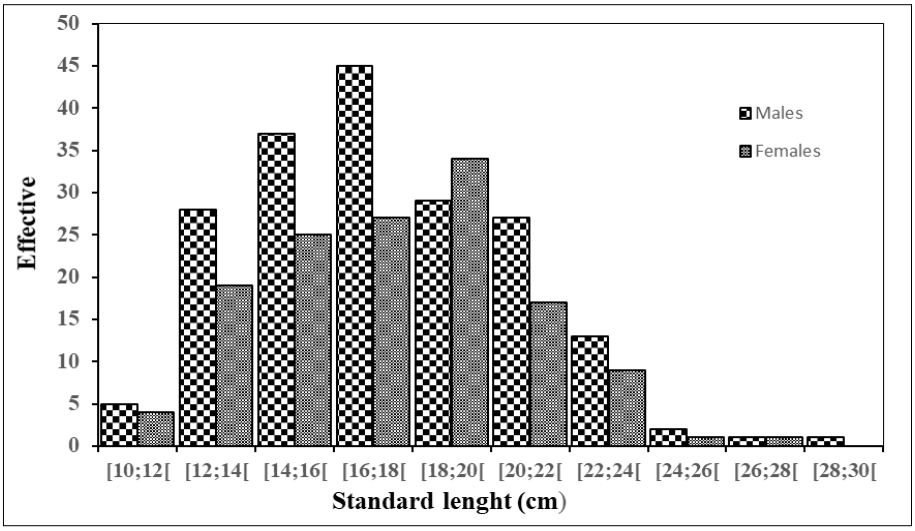

Fig 3: Distribution of size frequencies by sex of the population of *Malapterurus electricus* captured from August 2017 to July 2018 in the dam lake of Buyo (Côte d'Ivoire).

Size-Weight Relationship

The analysis of the size-weight relationship according to the log (MT) = b log (LS) + log (a) model at the population level of *Malapterurus electricus* is shown in Figure 4. The curve representing the change in weight versus standard length (LS) for 325 specimens is described by the following mathematical function: Log (MT) = 2, 9381*Log (LS) – 1.532. From this result, the value of the allometry coefficient b (slope of the regression line) obtained is 2.94. This value is significantly lower than the theoretical value 3 (Student *t-test*, $p<0.05$), thus reflecting a minor allometry at the level of the combined sexes (males and females). In other words, the total population of *Malapterurus electricus* grows more than it grows with a correlation coefficient (r) of 0.97.

For males, the curve representing the change in weight as a function of standard length (LS) is shown in Figure 5. From this curve, the mathematical function is: Log (MT) = 2, 9496 Log (LS) – 1.552. The value of the allometry coefficient b (slope of the regression line) obtained is 2.95. According to the test applied, this value is not significantly different to the theoretical value 3 (Student t-test, $p>0.05$), thus reflecting isometric growth of males. This means that *M. electricus* males have identical growth. They grow as well in weight as in height. The correlation coefficient r determined is 0.96. This shows that the weight is strongly correlated with the size of the species.

For females, the curve that reflects the change in weight versus standard length is shown in Figure 6. This curve is described by the following mathematical function: Log (MT) = 2.9180 Log (LS) – 1.500. From this function, the value of the allometry coefficient b (slope of the regression line) obtained is 2.92. This result shows that this value is significantly lower than the theoretical value 3 (Student t-*test*, $p<0.05$). Which translates into a minor allometry. This means that the females of *Malapterurus electricus* grow faster than they grow. The correlation coefficient r recorded is 0.97. This result shows that the weight is strongly correlated with the size of the species.

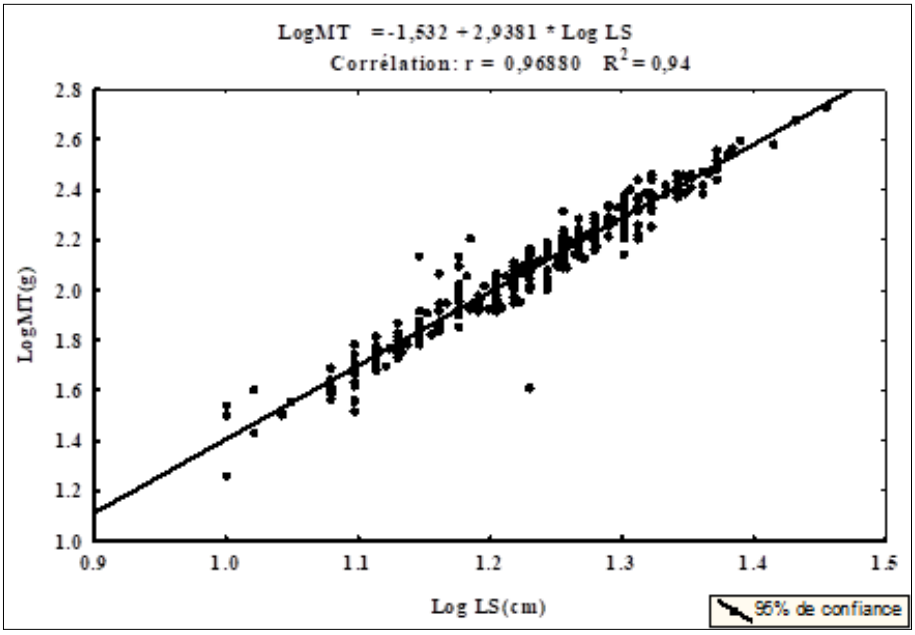

Fig 4: Length-weight relationship of males and females of *Malapterurus electricus* captured from August 2017 to July 2018 in the dam lake of Buyo (Côte d'Ivoire).

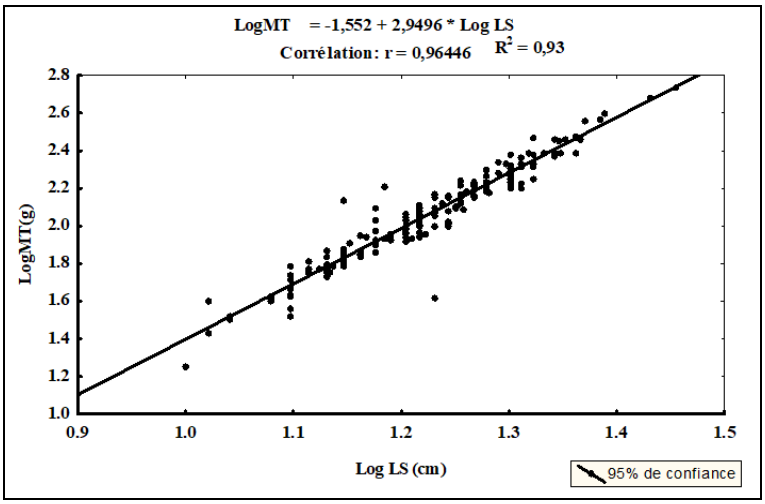

Fig 5: Height-weight relationship in males of *Malapterurus electricus* captured from August 2017 to July 2018 in the dam lake of Buyo (Côte d'Ivoire).

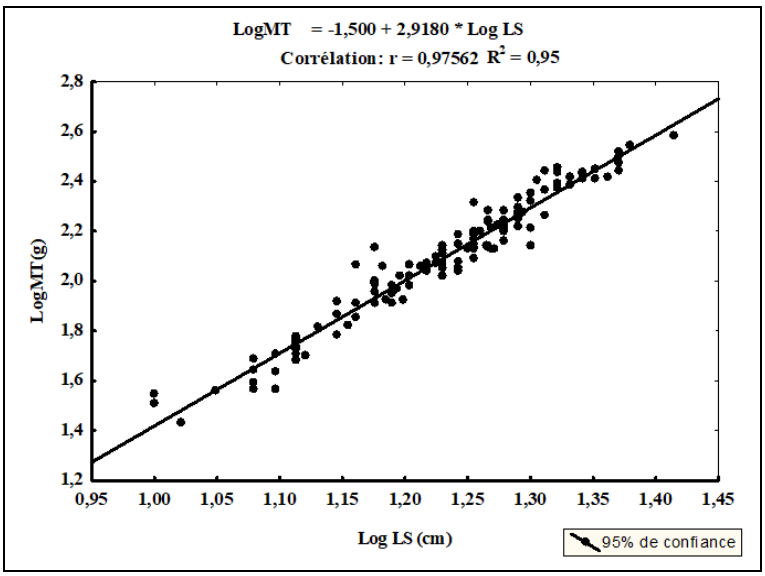

Fig 6: Height-weight relationship in females of *Malapterurus electricus* captured from August 2017 to July 2018 in the dam lake of Buyo (Côte d'Ivoire).

Study of reproduction

Sex-ratio

The result shows that of 325 specimens of *Malapterurus electricus* examined, there were 188 males and 137 females. The sex ratio (female: male) is 1:1.37 (Table 1). This sex-ratio obtained is not significantly different from the theoretical sex-ratio 1:1 (χ^2 =1.71; *p-value* > 0.05). In addition, significant monthly variations were observed (*p-value* < 0.05) in favour of females in November and in favour of males in August, October, February and March (Table 1).

Table 1: Monthly changes in sex and sex ratio for *Malapterurus electricus* captured from August 2017 to July 2018 in the Buyo dam lake in Côte d'Ivoire.

Month	Number of males	Number of females	Total	Sex-ratio F:M	
Aug-17	23	7	30	1: 3,28	20,09*
Sep-17	17	14	31	1: 1,21	0,67
Oct-17	21	9	30	1: 2,33	10,86*
Nov-17	11	19	30	1: 0,58	4,54*
Dec-17	18	12	30	1:1,5	2,67
Jan-18	9	12	21	1: 0,75	1,31
Feb-18	5	1	6	1: 5	30,52*
Mar-18	16	6	22	1 :2,66	14,45*
Apr-18	14	17	31	1: 0,82	0,67
May-18	18	15	33	1 :1,2	0,67
Jun-18	18	12	30	1: 1,5	2,68
Jul-18	18	13	31	1: 1,38	1,71
Total	188	137	325	1: 1,37	1,71

*: Significant difference; F: Female; M: Male

Height of first sexual maturity

The analysis in Figure 7 shows that the first sexual maturity size (SL50) of females and males is respectively 15.27 cm and 15.90 cm. These results show that no individual, regardless of sex, is mature to a size (SL) less than 15 cm. However, the smallest mature individuals caught have a size of 15 cm for females and 16 cm for males. The reliability of the results is justified by the χ^2 test. According to this test, there is no significant difference between the first sexual size of males and females (χ^2= 0,03; p>0,05).

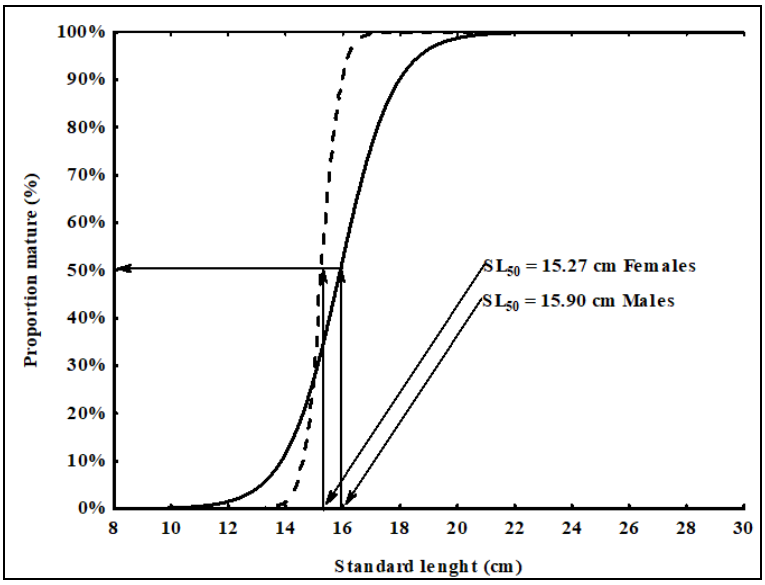

Fig 7: Evolution of the proportion of mature individuals in accordance with the standard length in females and males of *Malapterurus electricus* captured from August 2017 to July 2018 in the dam lake of Buyo (Côte d'Ivoire).

Condition factor (Kc)

The results showing the curve of the monthly variation of the condition factor (Kc) of *M. electricus* males and females are shown in Figure 8. In males, the mean condition factor obtained is 2,46 ± 0.39 while in females it is 2.53 ± 0.34. These results indicate that there is no significant difference (p>0.05) between male and female condition factors. For the monthly change in males, the highest mean value (2.70 ± 0.31) was recorded in February and the lowest value (2.29 ± 0.39) was recorded in August. For females, the highest mean value (2.64 ± 0.35) was recorded in January and the lowest value (2.31 ± 0.66) was recorded in March.

Gonado-somatic ratio and reproductive period

The monthly evolution of the gonado-somatic ratio (RGS) and the percentage of mature females are presented in Figure 9. The monthly average RGS monitoring of *M. electricus* females shows that in the Buyo dam lake, this parameter ranges from 0.46% in April to 4.61% in September. It has two peaks, of which the largest (4.61%) was recorded in September and the smallest (2.06%) was recorded in May. The highest proportions of mature females (50%) were recorded in July, August, September, October, February, March and May. Overall, the GSR increases from April to September and decreases from September to November. Over the period December to April, the value of the GSR is relatively low with a small amplitude of variation. For example, the change in the monthly mean GSR indicates that the April to November period is the breeding period and December to April is the sexual rest period for this species.

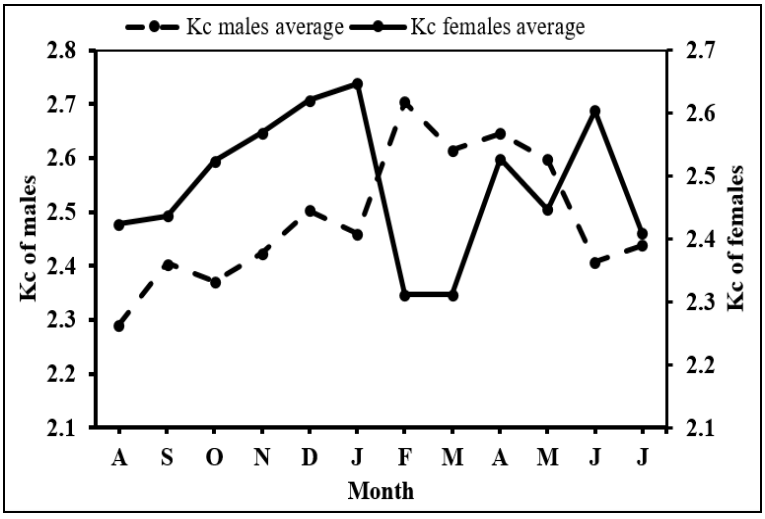

Fig 8: Monthly evolution of the mean condition factor (Kc) in males and females of *Malapterurus electricus* captured from August 2017 to July 2018 in the dam lake of Buyo (Côte d'Ivoire).

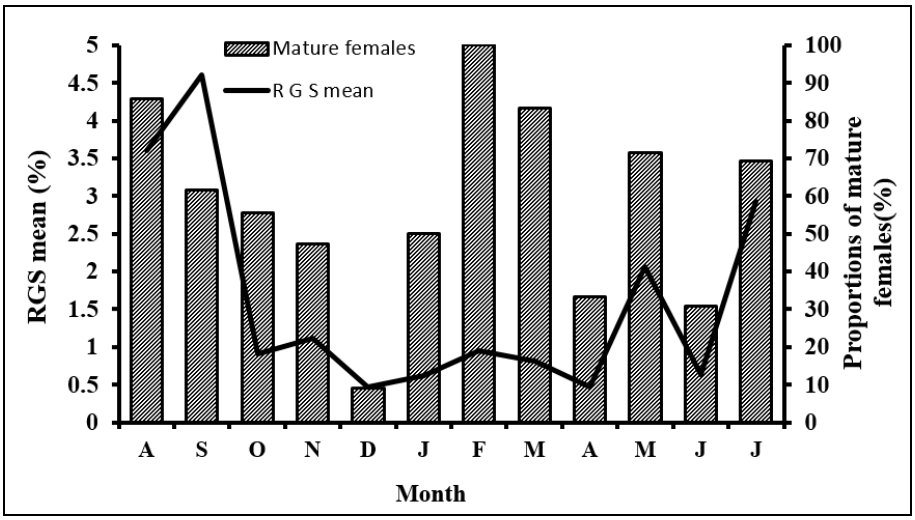

Fig 9: Monthly evolution of the mean gonado-somatic ratio and the percentage of mature females of *Malapterurus electricus* captured from August 2017 to July 2018 in the dam lake of Buyo (Côte d'Ivoire).

Fecundity

The results show that the estimated absolute fecundity ranges from 1016 to 3761 oocytes with an average value of 1813 ± 895 oocytes for specimens of females of standard length between 16 cm and 26 cm and weight between 96 g and 380 g. Relative fecundity ranges from 10 to 22 oocytes per gram body weight, with an average of 13.12 ± 5.19.

Discussion

The analysis of the data collection over the 12 months of sampling revealed that all the captured individuals of *Malapterurus electricus* have an average total length of 20.15 ± 3.84 cm varying by 11.5 cm to 34 cm and an average standard length of 17.08 ± 3.29 cm ranging from 10 cm to 28.5 cm for all sexes. Sex sampling indicates a mean size (SL) of 17.02 ± 3.32 cm for an average weight of 134.89 ± 82.90 g for males and 17.18 ± 3.26 cm for an average weight of 140. 84 ± 76.23 g for females. The results of this study are similar to the work of Arome and Garba (2007) [20] in the Benue River in Nigeria on the same species. According to these authors, the mean standard length of the males is 18.9 ± 1.49 cm and that of the females is 17.8 ± 0.43 cm. As for the mean weights, the mean weight of the males is 195.7 ± 50.4 g and that of the females is 130.1 ± 21.7 g. These observations are contrary to those of Bake *et al*. (2016) [21] in Agaie-lapai Dam Lake still in Nigeria. The work of the latter revealed that the total length of the *M. electricus* specimens ranges from 14.05 to 22.43 cm with a body weight ranging from 27.21 to 100 g for a standard length ranging from 11.85 to 19.93 cm for all sexes. The observed difference could be explained in the case of this study, the favourable environmental conditions, the abundance of food, the extent of the lake and its difficult capture. Bake and Sadiku (2012) [22] argue that these conditions easily contribute to the constant increase in weight and length of fish species.

As regards the face structure, the specimens of *M. electricus* collected in the Buyo dam lake show an unimodal distribution with a dominance of modal classes 16 to 18 cm. The face structure (SL) of the population by sex shows that males dominate most size classes especially sizes between 16 and 18 cm. In general, in Siluriformes, the most likely hypothesis advanced to explain the distribution of numbers by sex by size is the differential growth of males and females (Albaret, 1977) [23]. Growth parameters (size and weight) are very important in estimating biomass and fish production (Abba *et al*., 2013) [24]. That of this study, based on the size-weight relationship of *M. electricus* in the Buyo dam lake, showed that the female has negative allometric growth. This means that she believes more in height than in weight whereas the male has isometric growth, so grows as well in height as in weight. This means that at equal size, males weigh more than females. These observed results are contrary to those of Arome and Garba (2007) [20] in the Benue River in Nigeria, for which *M. electricus* has isometric growth with no apparent difference in the size of females and males. This difference in growth parameters could be related to living environment conditions, regular food presence and reproductive strategy (Abba *et al*., 2013) [24].

Regarding the sex-ratio, the overall catch of *M. electricus* fish species has shown that the sex-ratio is in favour of males. This predominance of one sex is a relatively common phenomenon in Teleostean fish species (Layachi *et al*., 2007) [25]. These observations are contrary to those of Arome and Garba (2007) [20] in the Benue River in Nigeria. These authors found a sex-ratio in favor of females. Several factors such as, displacement for food search, reproductive period, the mortality rate by sex and also the fact that males stay longer at the laying site because of the gradual emission of their sexual products could justify this predominance of males (Kartas and Quignard, 1984; King and Etim, 2004) [26, 27]. At the height of first sexual maturity, the values obtained in this study are 15.27 cm (SL) for females and 15.90 cm (SL) for males. There is no significant difference between the first sexual maturity size of females and males. However, females appear to reach sexual maturity faster than males. This difference in size at sexual maturity could be attributed to sex-related differential growth as in most teleosteans (Toguyeni, 1996; Abou-seedo and Dadzie, 2004) [28, 29]. Other factors such as increased fishing effort, misuse of fishing gear techniques, biological and/or ecological factors such as fish environmental condition and ecological stress could make a significant contribution to reducing the size of first sexual maturity (Wague and M'Bodji, 2002) [30]. The condition factor shows the well-being of the species in the environment. The study of these results indicates that there is no significant difference between the mean condition factor (2.46 ± 0.39) in males and that of females (2.53 ± 0.34). The results obtained differ from the work done by Bake *et al*. (2016) [21] on the

same species in the Agaie-Lapai dam lake in Nigeria. According to these authors, the condition factor of this species ranges from 1.13 to 1.93 with a mean value of 1.48 ± 0.22 at the level of males and females. However, the results of this study are similar to those of Arome and Garba (2007) [20] in the Benue River in Nigeria. The mean condition factors reported by these authors are 2.32 ± 0.02 in males and 2.09 ± 0.01 in females. This difference or similarity in condition factor could be related to the environmental conditions of the species. Examples include the presence of food, the degree of pollution, and the extent of water, because according to Laflamme *et al*. (2000) [31], the fish condition index is negatively affected by environmental contamination. Marchand *et al*. (2009) [32] also report that the presence of environmental pollution adversely affects food intake and decreases food resources (plankton and benthic macro invertebrates) available to fish. This clearly indicates that Lake Buyo is a favourable environment for the development of this species.

The monthly evolution of the GSR coupled with changes in the percentage of mature females shows that *M. electricus* sexual activity occurs from April to November in the Buyo Dam Lake. The highest values of GSR and percentage of mature females were observed during this period. The phases of prematuration, maturation and laying constitute the active period of the gonads. It is these different phases that determine the reproduction period of this species. The period from April to August is the period of sexual maturation and the period from September to November is the period of laying. In fact, the breeding season from April to November largely corresponds to the rainy season and the flood season of Buyo Dam Lake (Kouamé *et al*., 2008) [9]. Similar observations have been reported by some authors; Arome and Garba (2007) [20] in the Benue River in Nigeria and by Sagua (1979) [33] in Lake Kainji in Nigeria. According to these authors, the reproductive activity of *M. electricus* is maximal during the rainy season. In addition, Yalçin *et al*. (2001) [34] report that the reproductive activity of catfish is related to rainfall levels. According to Paugy (2002) [35], timing of the breeding season and the rainy season is a well-known strategy in many fish species in tropical areas. Indeed, this strategy allows juveniles not only to have shelter in submerged areas with the arrival of rains but also to have available food resources (Konan *et al*., 2013) [36]. However, the high percentage of mature females during the periods of February and March would be explained first by the scarcity of this species at that time and second by the low number of mature females obtained. Out of six individuals obtained in February, there were only 1 female. The only female obtained was mature. For the month of March, out of 22 individuals obtained, there were 6 females including 4 mature females. This justifies the high percentage of mature females in February and March.

However, the fecundity study revealed that *M. electricus* is a highly fertile species. The mean absolute fecundity obtained in the Buyo dam lake is 1813 oocytes. This value is lower than those observed by Arome and Garba (2007) [20] in the Benue River and by Sagua (1979) [33] in Lake Kainji in Nigeria for the same species with 2331 and 23000 oocytes respectively. This difference could be explained by factors such as hydrological conditions, overfishing and overexploitation of the stock resulting in little development of these fish species (Layachi *et al*., 2007) [25].

Conclusion and Recommendations

This study is a contribution to the knowledge of the growth and reproduction parameters of *Malapterurus electricus* in the dam lake of Buyo (Côte d'Ivoire). This study showed that the sex ratio is in favour of males. Females reach sexual maturity before males. The condition factor indicates that the species is well overweight in this environment. *M. electricus* breeds from April to November in the dam lake of Buyo. For the sustainable management of the existing stock and for the preservation of *M. electricus*, measures such as prohibiting the use of small mesh fishing gear and partial closure of the lake during the breeding season of the species of at least three (3) months from August to November must be taken by managers in this area. These measures are necessary to ensure the sustainability of the species as well as the conservation of the Ichthyological fauna of the dam lake of Buyo (Côte d'Ivoire).

Acknowledgements

This study was conducted as part of the project entitled "Scientific Studies for the Purpose of Proposing National Regulations for the Rational Use of Inland Water Fisheries Resources", project financed by the Support Programme for the Sustainable Management of Fisheries Resources (PAGDRH) of the Directorate of Aquaculture and Fisheries (DAP). The authors would like to thank all those who facilitated the project. They are grateful to Mr Goli -Bi Binta Eric Pacôme and to all the research teachers of the Laboratory of Hydrobiology and Water- Ecotechnology of the UFR Biosciences of the University Félix HOUPHOUËT-BOIGNY in Côte d'Ivoire for their assistance in data collection. We also do not forget the fishery officers respectively their various officials Lieutenant Kamagaté Beman (Buyo), the postmaster N'guessan Gontran (Guessabo) and the fishing community of the localities of Guessabo-Buyo and PK 15 for their effective cooperation.

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