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BREEDING STRATEGY OF *Nannothrissa stewarti* POLL & ROBERTS 1976 CLUPEIDAE IN LAKE MAI-NDOMBE, DEMOCRATIC REPUBLIC OF CONGO

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Abstract

Background. Clupeidae, *Nannothrissa stewarti* (Poll & Roberts 1976) endemic to Lake Mai-Ndombe is one of most heavily fished fish groups using practices and nets not allowed by the country's legislation. Objective of this study was to determine some aspects of reproductive biology of *N. stewarti* in Lake Mai-Ndombe.

Materials and methods. Fish were sampled monthly from November 2020 to October 2021 breeding parameters were determined : Gonado-somatic index (GSI), Size at first sexual maturity, Absolute fecundity and the relationship between total weight (WT) and total length.

Results. Results obtained showed that the sex ratio was in favor of females (1 : 0.8). Estimated absolute fecundity was between 227 and 4080 oocytes for females of total length between 23 and 35 mm with an average of 923 ± 664 g oocytes and a relative fecundity varying between 25115 and 155457 oocytes kg-1. Average oocyte diameter was 0.20 ± 0.14 mm. Distribution of oocyte diameters observed in the population as well as monthly variations of the Somatic Gonado Index (SGI) indicate that the species has two main clutches during the year. LT_{50} size at first sexual maturity is 27.6 mm for males and 25.5 mm for females.

Conclusion. *N. stewarti* from Lake Mai-Ndombe has multiple reproduction throughout year with however two maximum peaks at the beginning of peak rainfall (February-March and September-October).

Keywords: Fecoundity, First sexual maturity size, GSI, Maturity stage, Sex ratio, Oocyte diameter

Introduction

Fish reproduction is one of the most complex aspects of their biology. As in most vertebrates, it is a cyclical phenomenon whose annual periodicity is often influenced by environmental and endocrine conditions that affect gonadal maturation, development of primary, secondary sexual characters and reproductive behavior (Bouhali et al. 2015).

The Clupeidae, *N. stewarti* (Poll & Roberts, 1976) endemic to Lake Mai-Ndombe (Musschoot et al. 2021) is among the most heavily fished fish groups (IUCN 2022) using practices and nets not allowed by the country's legislation as lake Tumba (Zanga et al. 2019). This fish is sold in various ports in the town of Inongo and throughout the settlements around the lake, that sttlement earn money from that solved their social and economic needs (Béné et al. 2009). It is prized by the local populations and is the object of important catches varying between 1.9 and 28.1 kg per haul, i.e., a daily catch of between 10.03 and 58.40 kg/day/2 hauls senne/day, i.e., an average of 32.2 kg/d/2 hauls and a monthly average of 644 kg/60 hauls senne/month (Micha et al. 2020). Provide food for millions of people in one of the world's poorest regions (De Keyzer et al. 2019)

Unfortunately, to our knowledge, few studies based on the fishery resources of Lake Mai-Ndombe have been undertaken except Luhusu & Micha (2013) and information on the reproductive biology of *N. stewarti* is almost non-existent. However, information on the reproduction of *N. stewarti* in Lake Mai-Ndombe can be used to consider stock assessment models on the one hand and management decisions to plan the rational use and protection of fishery resources on the other (Heins et al., 2004). Determining the size at first sexual maturity and the periods of peak reproduction will allow to advise the fishermen the types of gears and period of the year the fishing of the species can be done to avoid the depletion of stock especially that the species is endemic (Olayinka 2018)

The objective of this study is to determine some aspects of the reproductive biology and a single variable of croissance of *N. stewarti* in Lake Mai-Ndombe. More specifically, it aims to specify: sex ratio, Gonado-Somatic Index (GSI), fertility, oocyte diameter and size of first sexual maturity and the relationship between total weight (WT) and total length.

Materials and methods

This study was conducted in Lake Mai-Ndombe Fig. 1 located at 18° 14' East and1° 53' South. This lake is 146 km long, 18 km wide and covers 2300 Sqkm. The fish were sampled using two types of monofilament nets of 0.1 cm and 2.5 cm knots, 500 m long and 2 m drop, put together was active technique and hauled for 3 hours in a single haul per day once a month each site. The fishing starts at 5 o'clock in the morning. The fishing is done at the same time for each sampling site. The sampling points were determined in a random way and according to the size of the lake.

The biological material for this study consists of 688 specimens of *N. stewarti* caught in Lake Mai-Ndombe between November 2020 and October 2021.

The Lake Mai-Ndombe region has an Af-type climate according to the Köppen classification (Bultot & Griffits 1971). The monthly diurnal air temperature ranges from 25.96 to 27.25°C, with an average of (26.4 ± 0.49°C). Monthly air temperature ranges from 25.69°C to 27.3°C with an average of 26.49 ± 0.44°C. Monthly rainfall varies from 69.91 mm to 153.61 mm with an average of 115.42 ± 28.16 mm. Annual precipitation ranges from 1000.9 mm to 1740.7 mm. Fig. 2 shows the umbrothermal diagram for this region for a period of 41 years. Analysis of this diagram indicates that the Lake Mai-Ndombe region does not experience a marked dry season, although a decrease in rainfall is recorded in June and July.

The waters of Lake Mai - Ndombe have an acidic pH between 3.94 and 4.05 and are not very transparent 0.5 and 0.8 cm with potassium ion (K^+) contents between 0.006 and 0.010 meq/L(miliequivalent per liter). Phosphate ion ($PO4^{-3}$) concentration is less than 4 µg/L and silica (Si^{+4}) concentration in the range of 1.2 mg/L. The ammonium nitrogen ($NH4^+$) concentration is on the order of 21 µg/L (Micha et al. 2020).

According Belesi (2016), (macrophytic) vegetation of Lake Maï-Ndombe is characterized by *Loudetia phragmitoides* - *Andropogon schirensis* and *Fimbristylis dichotoma* - *Solenostemon monostachyus* groupings. Flooded forest vegetation, such as *Zeyherella longipedicellata*, dominates the vegetation cover. We note the frequent

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presence of *Cleistanthus ripicola*, *Guibourtia demeusei*, *Parinari congensis*, *Plagiostyle africana*, *Uapaca heudelotii, Zeyherella longipedicellata*.

The phytoplankton, is dominated by chrysomonales, chlorophyceae (green algae), diatoms, flagellates and cyanophyceae (Micha et al. 2020). Zooplankton are characterized by copepods, cladocerans, and rotifers.

As for fishes, there are about fifty species. The emblematic families are Clariidae, Channidae, Clupeidae, Mormyridae, Claroteidae, Cichlidae, Alestidae.

The relationship between total weight (WT) and total length (TL) is represented by the relationship (Sossoukpe et al. 2016a):

$$\mathbf{TW = a\ TL^{b}}$$

Where TW = total weight of the fish in g; Lt = total length of the fish in mm; a = a constant and b = allometric rate.

The sex ratio (SR) is used to evaluate the demographic structure and the spawning biomass of the stock. The numerical proportion of the sexes is expressed by the ratio of the number of males to the number of females. The males are characterized by the testicles and the females are characterized by the ovary differentiated or not according to the stage of maturity. It is determined by the equation (Berchie et al. 2020):

Sex ratio (SR) is determined from the following equation:

$$SR = \frac{\text{Number of males}}{\text{Number of females}}$$

GSI was calculated from the following formula (Kone et al. 2016):

$$GSI = \frac{Wgo}{TW} * 100$$

Where: Wgo = gonad weight (g); TW = total fish weight (g) and GSI = Gonado Somatic Index.

Gonads were classified into different stages of sexual maturity according to the conventional maturity scale (Berchie et al. 2020). Only fish in maturity stages III, IV and V were considered for this study.

The size of first sexual maturity is defined as the size (L_{50}) at which 50% of individuals of both sexes in the study population have reached sexual maturity.

The L_{50} is determined from the equation of the sigmoid curve of the evolution of the percentages (P) of sexual maturity as a function of the size classes (TL). This curve is obtained by logistic transformation according to Dagnelie (1973) and is given by the formula:

$$P = \frac{X}{(1+X)}$$

Avec : $X = e^{(a+bLt)}$,

a and b : being coefficients of the model. The logarithmic transformation of the equation allows to put it in the form :

$$\ln (P/1-P) = a+bLt$$

In which L_{50} is obtained by the formula L_{50} by replacing : P = 50 %. For this purpose, we used Origin 6.1 software which allows to obtain all logarithmic transformations and the sigmoid curve.

The number of mature eggs in the gonads was determined by counting oocytes in an ovary fraction under a Wild Heerbrugg 113099 binocular loupe at 10X magnification and then reported to the total gonad weight (Dadébo et al. 2003). It was estimated according to the following formula:

$$F = (n*Wgo)/W_{sample}$$

With: F = Individual fecundity per egg-laying act; n = Number of oocytes contained in the ovary sample; Wgo = Total ovary weight (g) and Wsample = Ovary sample weight (g).

Relative fecundity was calculated using the following expression:

$$F_r = F/W$$

Where: Fr is relative fecundity; F absolute fecundity and W somatic weight (g) (Berchie et al. 2020).

To determine the diameter (mm), 30 oocytes in stage IV were measured under a binocular loupe equipped with a micrometer (model MG 10085-1). The average diameter was determined from the arithmetic mean of the measurements made (unit of the ocular micrometer at 10 x magnification). To do this, the collected gonad fragments were weighed, then fixed in modified Gilson's liquid (100 ml 60% alcohol + 800 ml distilled water and 15 ml 80% nitric acid + 18 ml glacial acetic acid + 20 g mercuric chloride) for 24 hours.

This operation promotes the dissociation of oocytes and thus allows them to be isolated from each other in order to count them.

The absolute fecundity-gonad weight relationship is determined from the relationship from the following absolute fecundity-gonad weight linear regression equation:

$$F = a\ L^b,\ \log F = b \log L.$$

$$F = a\ W^b \text{ Donc : } \log F = b \log W.$$

Where: F = absolute fecundity, a = coefficient of the equation of X, b = the coefficient of Y, L = length, W= weight

Tembeni et al. (2014) established the fecundity-length relation which describes in a satisfactory way the relation between fecundity and length: $F = aLt^b$.

After logarithmic transformation, the relationship becomes linear: $\ln F = \ln a + b \ln Lt$.

We can then fit the resulting scatterplot into a linear regression line (by the least squares method) and derive the values of the coefficients a and b.

The relationships "absolute fecundity (F) - total length (TL)" and "absolute fecundity (F) - total weight (TW)" are obtained by the equations: $F = a + bTL$ and $F = a + bTW$, a and b being the coefficients of the fitted lines.

The computer software Statistix version 10 trial, Origin version 6.1, Past 4.03 and Excel were used to analyze and process the data.

Results

Measurement

The total length of the males varied from 20.6 to 38.5 mm, average 28.77 ± 4.56 mm and the weight between 2 and 10.54 g, average 5.02 ± 2.06 g. As for the females it was between 20.6 and 49.84, average 32.43 ± 4.5 mm. The weight was between 1.74 and 12.52, average 6.36 ± 2.25 g.

The relationship between total weight (g) and total length (mm) of males and femala is given in Fig. 3 for *N. stewarti.*

The relationship between total weight and total length of the fish (Figure 3, a and b) shows a very high and highly significant correlation coefficient (*p*-value < 0.0001): r = 87 for females and r = 87 for males).

Reproductive features

The determination of the sex ratio involved 591 specimens of *N stewarti* of which 262 were males and 329 females. The sex ratio is (1 : 0.8), that is 1 female for 0.8 males.

The evolution of the Somatic Gonado Index of *N stewarti* specimens shows several peaks Fig. 4.

The GSI varied from month to month. In females, two peaks were observed: in April 2021 (9.77 ± 2.19) and August 2021 (10.55 ± 2.19). Low values of (IGS) were observed in February 2021 (4.07 ± 2.19) and December 2020 (4.41± 2.19). In males, two peaks were also observed: in June 2021 (6.37±1.41) and October 2021 (4.83±1.41) and the lowest values in March 2021 (1.54±1.41) and December 2020 (1.86±1.41) Fig. 4.

The evolution of the maturity stages of *N. stewarti* specimens sampled in Lake Mai Ndombe is visualized in (Fig. 5 and 6).

Male gonads begun to develop in March and December, maturity was then observed every month except July, September and October Fig. 5. Female gonads begun to develop in December, February, and March stage I. Stage II evolves from February to December. Stage III, the beginning of maturity, was encountered during most of the year, except for the months of May, August and September. The stage IV, maturation and expulsion of the gametes, is observed all the months of the year. Stage V, which corresponds to the resting stage, was not so visible Fig. 6.

The size of first maturity (L_{50}) for males and females of *N. stewarti* is presented in Fig. 8.

In females of *N. stewarti* the size of first sexual maturity (L_{50}) was reached at 25.5 mm (Total length) and at 27.59 mm in males Fig. 7.

The estimated absolute fecundity for *N. stewarti* was varied from 227 to 4080 oocytes for females with total length between 23 and 35 mm with an average absolute fecundity of 923 ± 664 oocytes.

Estimated relative fecundity was ranged from 25115 to 155457 oocytes kg-1 of total body weight with a mean of 161504 ± 87887 kg-1.

The values of the diameters of the oocytes in stage III and IV found in the fish was ranged from 0.1 to 0.5 mm with a mean of 0.2 ± 0.14 mm. Figure 8 visualizes the annual oocyte diameter distribution of *N. stewarti*.

The distribution of histograms was shows two peaks in oocyte diameters, suggesting two main oviposition events during the year for *N. stewarti* in Lake Mai-Ndombe.

The relationship between absolute fecundity and total length (mm) of *N. stewarti* is shown in Fig. 9.

The equation relating absolute fecundity and total length, after log transformation, is of linear type, with a highly significant relationship between the two parameters ($r = 0.86$) (*p* at the 0.05 < 0.0001 significance level).

The relationship between absolute fecundity and total weight (g) of *N. stewarti* was visualized in Fig. 10.

The absolute fecundity - total weight relationship, after log transformation, was linear with a high regression coefficient ($r = 0.85$) and highly significant (p at the 0.05 < 0.0001 significance level).

Discussion

Specimens of *N. stewarti* studied in Lake Mai-Ndombe measured between 23.0 and 49.84 mm in total length and weighed between 2 and 12.52 g. These sizes are close to those obtained by Kolding et al. (2019) on *Microthrissa moeruensis* Poll, 1948 (Clupeidae), endemic to Lake Mweru in eastern DRC and that of *Pellonula leonensis* Boulenger, 1916 and *Sierathrissa leonensis* Thys van den Audenaerde 1969, a small African Clupeidae known as a pygmy herring. These size differences would result from long adaptation/evolution in these various environments but may also result from their levels of exploitation and the mesh size of the fishing nets used.

The sex ratio of *N. stewarti* fish (262 males and 329 females) is in favor of females (1 : 0.8), i.e. 1 female for 0.8 males. Females were slightly numerous than males predominance of one sex is a relatively common phenomenon in many teleost fish species. Variations of the sex ratio according to size have a considerable impact on the fertility of stocks according to whether the adult individual majority captured is female or male. However, the sex ratio is influenced by many factors several factors such as movement for foraging and spawning, differential growth, and sex-specific mortality rates also influence the sex ratio in fishes. High catchability of females, higher natural mortality in males, or simply differential growth of individuals may also explain this sex ratio. However, our results show that this is not a sexual difference in growth, as the weight-length relationships are quite similar. Our observations are similar to those made on *P. leonensis*, in the Kossou dam lake in Benin and Côte d'Ivoire where Sossoukpe et al. (2016 a) ; noted that the overall catch of *Sardinella maderensis* Pisces Lowe, 1838 and *P. leonensis* was dominated by females. The difficulties of determining the sex of immature and hermaphrodite individuals could greatly affect the proportion of males and females obtained. But a revers result was recorded with a sex ratio of 1.3:1 in favour of males by Berchie et al. (2020) in the studies of *Ilisha africana* Bloch, 1795 from the coast of Ghana West Africa.

The absolute fecundity value calculated for *N. stewarti* ranged from 227 to 4080 oocytes for females with total length between 23 and 35 mm. The estimated relative fecundity in *N. stewarti* ranges from 25115 to 155457 oocytes kg-1. These relatively high fecundity values place *N. stewarti* in the rank of prolific species with high fecundity, which produce many small eggs and invest several times per year in ovarian production (high IGS). In addition, Kolding et al. (2019) obtained similar results to ours in Nigeria in the study conducted on *P. elongatus*. This high fecundity also places this fish in the group of individuals with a reproductive strategy (r), which allows it to take advantage of any momentarily abundant sources in the lake (zooplankton boom) (Sylla 2009). This feccundity could be attributed to a number of factors including availability of food resources, sizes and age of specimens examined, season and specific environmental conditions noted the disparity in fecundity among populations of a given fish species as adaption to different environmental conditions that produce higher or lower survival opportunities for the species intense, fishing presure, strong water acidity and other human perturbations (Aniefiokmkpong et al. 2020).

Information about gonadal development and the spawning season of a species plays a significant role in determining the spawning frequency of its population, which is critical for its management (Hasan et al. 2018; Adaba and Lilian 2018). During the year, the GSI of females and males show a sawtooth variation. In any case, the energy allocation attributed to the constitution of genitalia appears to be less important for males than for females. These results are consistent with those obtained by Abekan et al. (2017) on the study of *Auxis thazard* Lacepède, 1800 caught in the Gulf of Guinea by the Ivorian artisanal fleet. Two peaks are evident for the females, the first in April and the second in August. However, males show them in June and October. The constant is that these variations in females are synchronized with the high hydrology related to the two peaks. Variation in spawning periods with regards to other studies may be due to regional variation as well as other environmental factors (Hasan et al. 2018).

The major spawning seasons of male and females observed from the current study was found to have occurred in the period for the high increase in zooplancton and phytoplankton. As a result, the increase in phytoplankton biomass may be viewed as one of the environmental drivers for an approaching favourable season for better growth and survival of fish. In males the first peak occurs during the June rainfall decrease, when the hydrological level is low Fig. 2. In addition, sexual maturity stages and oocyte diameters follow the same variations, especially since they are linked to the evolution of the GSI. The maturity scales characterize the different states presented by the ovaries and testes during their evolution corresponding to that of the GSI. Figs 5 and 6 show oocytes of different sizes corresponding to the different stages of development. Oviposition is probably performed throughout the year but with two more important peaks corresponding to the observed bimodal distribution. These results are consistent with those obtained by Ezenwaji and Offiah (2003) in the Anambra River in Nigeria, Sossoukpe et al. (2017b) in the study of clupeidae from Beninese waters and by Osei et al (2020) in Ghana cost. This situation is observed in the area near the geographical equator where it rains almost all year round. Mulimbwa et al. (2022), determined in their studies at Lake Tanganyika the breeding peaks for *Limnothrissa miodon* Boulanger, 1906 in the months of January, April and October. Whereas *Stolothrissa tanganicae*, also endemic to Lake Tanganyika, has a small peak in January and March and then another peak in June-July. These similarities and differences may be due to the physico-chemical variations of the waters (hydrology, hydrodynamics, transparency, temperature, concentration of mineral salts), the level of production of plankton, the genetics of the species and the synchronization of the climate with the reproductive cycle of the fish species (Kone et al. 2016).

Environmental conditions such as winds in February, March, April, September, October and November are dominated by strong winds that cause water mixing, bringing nutrients to the surface, allowing primary and then zooplanktonic production, probably favorable to Clupeidae larvae. Rainfall also brings additional nutrients from the watershed stream. They cause algal production which results in high biomass of zooplankton. Zooplankton is the main food of *N. stewarti*, and the larvae of Clupeidae feed on *copepod nauplii*. This abundance of zooplankton could contribute to the turnover of *N. stewarti* cohorts successively for several months during the year. Our results show that the reproductive investment of *N. stewarti* was high during high water in February, March, April, May, August, September, October, November and December and synchronized with high rainfall and temperature periods that coincide at the same time with peak plankton abundance Mulimbwa et al. (2022). The success of several cohorts of *N. stewar*ti thus seems to be linked to higher temperature and rainfall causing the abundance of phytoplankton (diatoms) and zooplankton (cladocerans, copepods, rotifers) Amin et al. (2016). Variables such as stage of maturity and oocyte diameters follow the same fluctuations and therefore produce the same effects.

N. stewarti females from Lake Mai-Ndombe reach their first sexual maturity (L_{50}) at 25.5 mm (TL) while males reach it at 27.59 mm (TL). Average length of males where 28.77 ± 4.56 mm and females 32.43 ± 4.5 mm comparing these values with the length of the first capture in the present study, it appears that *N. stewarti* of Lake Mai-Ndombe black waters reaches the size of first sexual maturation before its first capture.This particularity is linked to genetic factors of the species as well as to environmental and ecological factors: food, water conductivity, temperature, and predation. Hasan et al. (2018) stated that the maturity of a fish relies on its growth rate, and for this reason, a stunted fish will be sexually mature at a small size whereas a fast-growing fish will attain maturity at a much larger size. Amin et al. (2016) several environmental conditions might have changed and thus, affecting the sexual maturity of the fish. For the sustainability of the fish stock, Isangedighi and Ambrose (2015) demonstrated that larger fishes are bound to produce more eggs. To support the claim by Isangedighi and Ambrose (2015), indicated that the fecundity of *N. stewarti* increased with fish length and weight. Based on this, the relatively smol length at first maturity of the species (both male and female) in the current study may be viewed as a négative reproductive characteristic leading to the overfishing and decreasing of its stock fishes in Lake Mai-Ndombe. These elements push the species to develop an adaptation system to perpetuate its offspring. These results are similar to those of Bouhali et al. (2015); Kolding et al. (2019), Mulimbwa et al. (2022) on *S. tanganicae* and *L. miodon*, African Clupeidae endemic to Lake Tanganyika. *Sierrathrissa leonensis* in Ghana and

Nigeria reached its first maturity size at 24 mm. According to Osei et al. (2020) this early maturity could be justified by the capacity of the reproducers to adapt to environmental factors such as temperature, salinity and trophic resources as well as the internal conditions of the fish, its endocrine metabolism (pituitary and hypothalamus). It also contributes to promote the r strategy of *N. stewarti*, which, given its abundance and resilience to net seine fisheries, is perfectly efficient in this Mai-Ndombe lake so a best management conditions should tooks place (Jufaili 2021).

Conclusion and perspectives

This study took place in Lake Mai-Ndombe in the Democratic Republic of Congo and had the overall objective of determining some aspects of the reproductive biology and a single growth variable of *N. stewarti* in Lake Mai-Ndombe. Specifically, the aim was to determine: sex ratio, gonado-somatic index (GSI), fertility, oocyte diameter and size at first sexual maturity and the relationship between total weight (TW) and total length. The results obtained show a sex ratio of (1: 0.8), i.e. 1 female for 0.8 males. The GSI in females, two peaks were observed: in April 2021 (9.77 ± 2.19) and in August 2021 (10.55 ± 2.19). In males, two peaks were also observed in June 2021 (6.37±1.41) and October 2021 (4.83±1.41). Male gonad maturity was then observed in all months except July, September, and October, early maturing female gonads were encountered for most of the year except during May, August, and September. In *N. stewarti* females the size at first sexual maturity (L50) was reached at 25.5 mm (total length) and at 27.59 mm in males. Estimated absolute fecundity for *N. stewarti* ranged from 227 to 4080 oocytes for females with total length between 23 and 35 mm with an average absolute fecundity of 923 ± 664 oocytes. Estimated relative fecundity ranged from 25115 to 155457 oocytes kg-1 of total body weight with a mean of 161504 ± 87887 kg-1. The values of stage III and IV oocyte diameters found in the fish ranged from 0.1 to 0.5 mm with a mean of 0.2 ± 0.14 mm. In the interest of preserving the species, information on the reproduction of *N. stewarti* in Lake Mai-Ndombe was elucidated and can be used to consider stock assessment models on the one hand and management decisions to plan the rational use and protection of fishery resources on the other hand. Determining the size at first sexual maturity and the periods of peak reproduction will allow fishermen to be advised on the types of gear and period of the year the species can be fished to avoid stock depletion, especially since the species is endemic. The political-administrative authorities of the province of Mai-Ndombe are called to adopt and apply the texts which will have to govern the participation of the populations to observe the conservation of the aquatic resources of this ecosystem.

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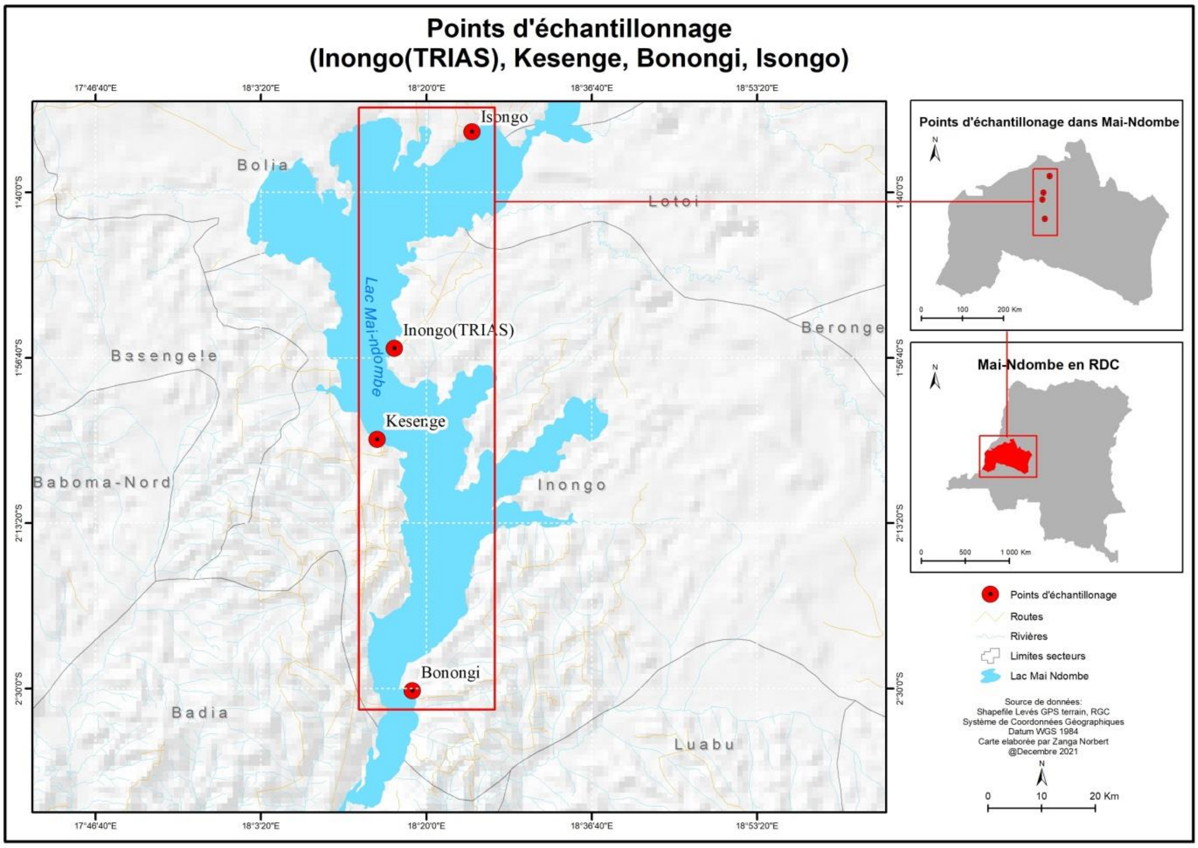


Figure 1. Map of Lake Mai-Ndombe showing study four sites in red dots

In folowing Fig. 2 illustred two weathers variables temperature and precipitation which desrcibe season in study area.

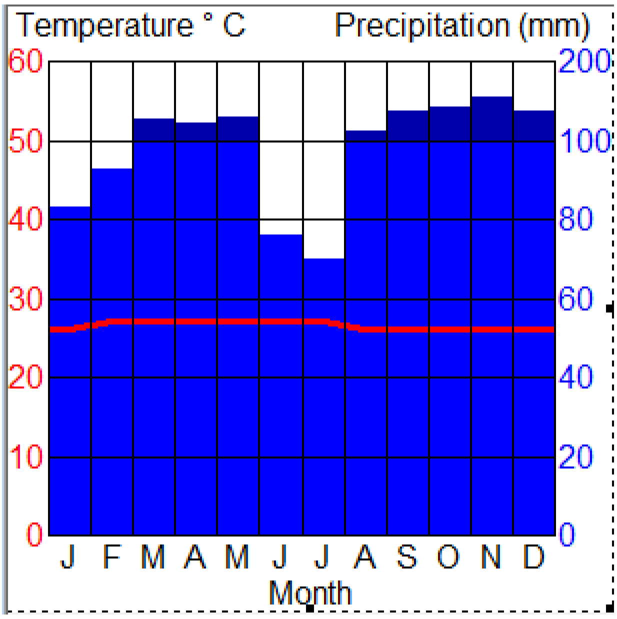
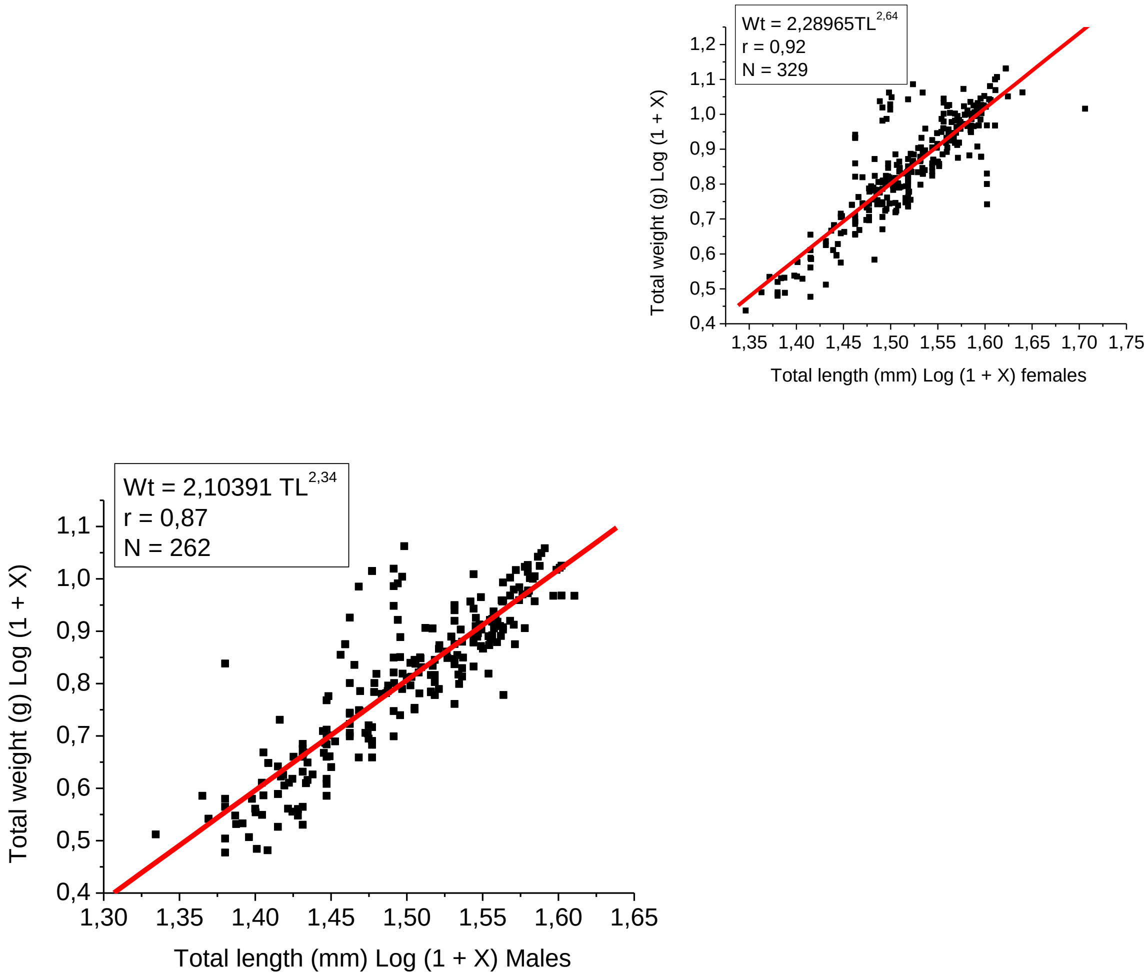


Figure 2. Umbrothermal diagram of the Lake Mai-Ndombe region

The relationship between total weight (g) and total length (mm) of males and femala is given in Fig. 3 for *N. stewarti.*



3. a 3. b

Figure 3 a and b. Total weight - total length relationship after log transformation in females and males of *N. stewarti* in Lake Mai-Ndombe.

The evolution of the Somatic Gonado Index of *N stewarti* specimens shows several peaks Fig. 4.

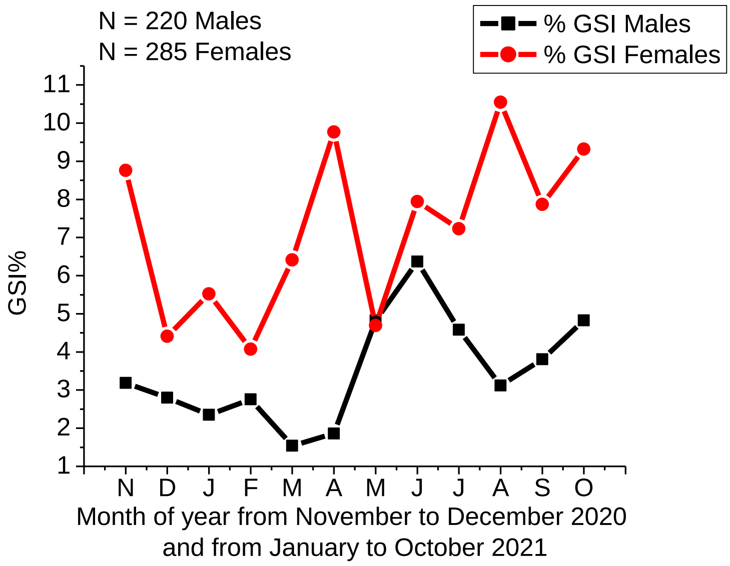


Figure 4. Monthly evolution of the average Gonado-Somatic Index of male and female *N. stewarti* from November 2020 to October 2021 in Lake Mai-Ndombe

The evolution of the maturity stages of *N. stewarti* specimens sampled in Lake Mai Ndombe is visualized in (Fig. 5 and 6).

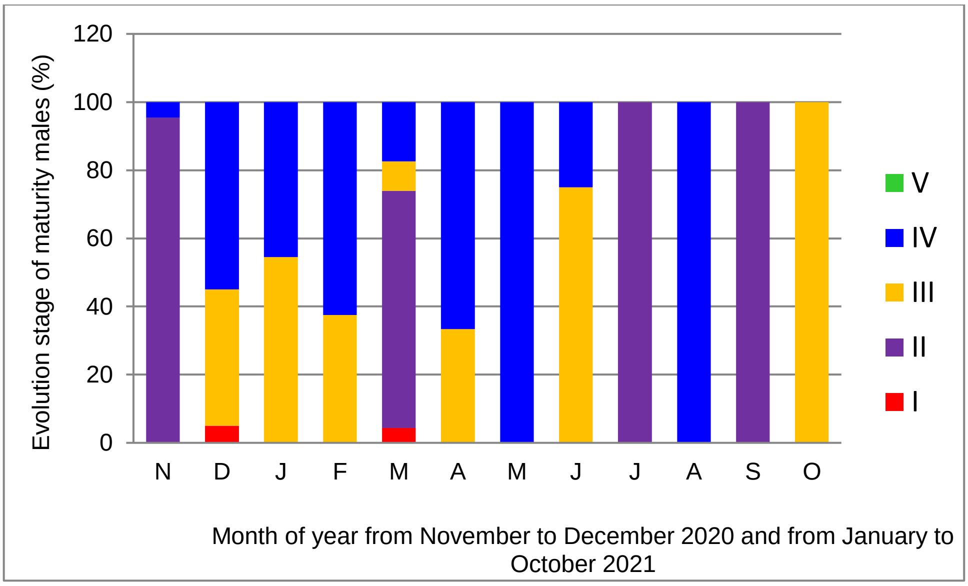


Figure 5. monthly evolution of sexual maturity stages of males *N. stewarti* between November 2020 and October 2021.

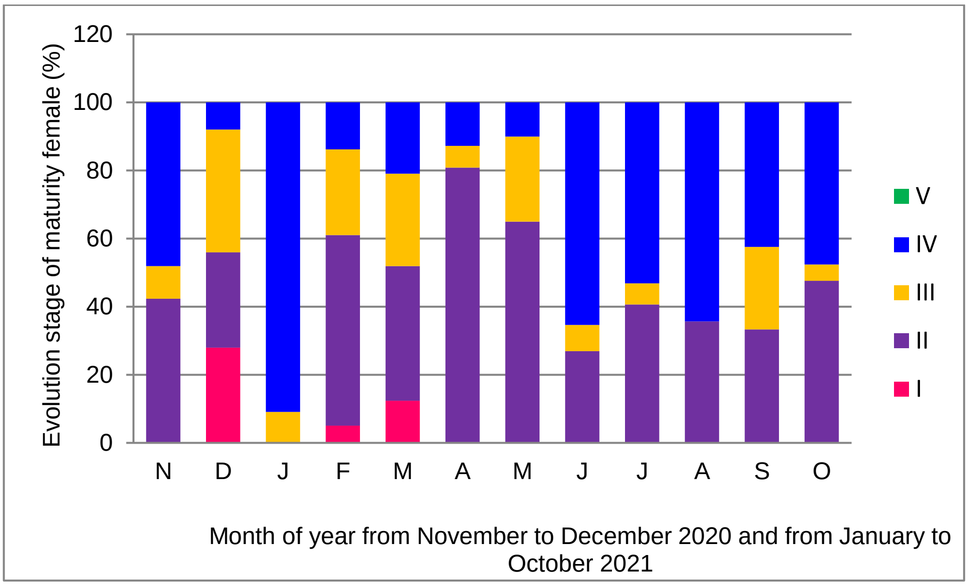
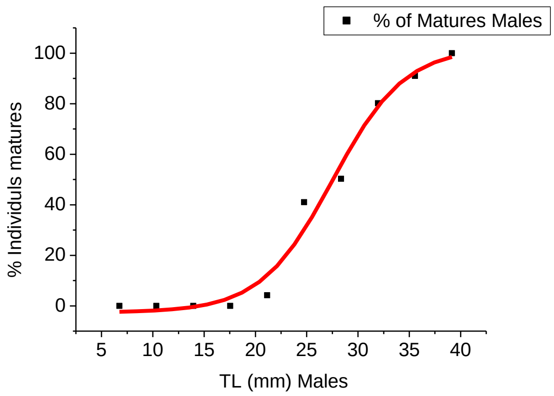
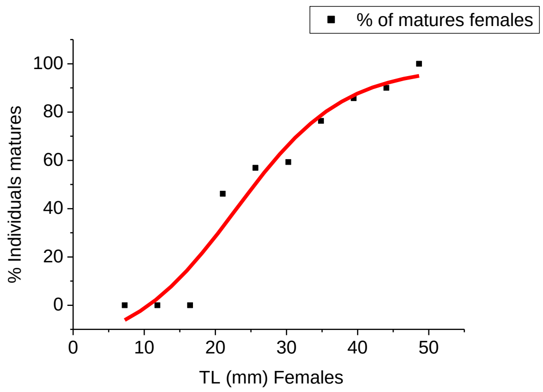


Figure 6. Monthly evolution of sexual maturity stages of females *N. stewarti* between November to December 2020 and from January to October 2021.

The size of first maturity (L_{50}) for males and females of *N. stewarti* is presented in Fig. 7.





a *N. stewarti* males

b. *N. stewarti* femalles

Figure 7. Determination of the size of first sexual maturity (L_{50}) in male (a) and female (b) *N. stewarti*.

Fig. 8 visualizes the annual oocyte diameter distribution of *N. stewarti*.

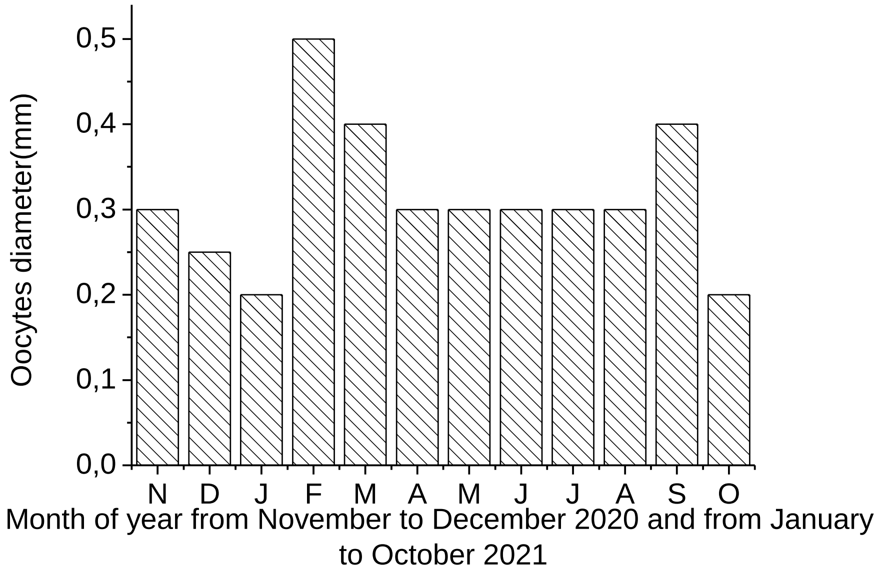


Figure 8. Oocyte diameters of *N. stewarti* sampled from November to Décemebr 2020 and from January to October 2021 in Lake Mai-Ndombe.

The relationship between absolute fecundity and total length (mm) of *N. stewarti* is shown in Fig. 9.

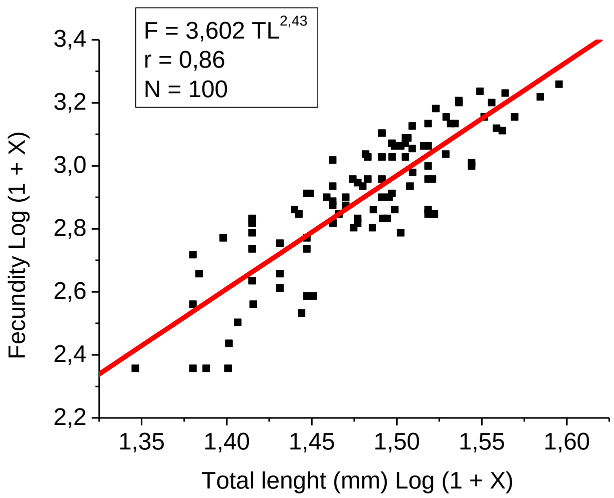


Figure 9. Relationship between absolute fecundity and total length after logarithmic transformation in *N. stewarti* females caught in Lake Mai-Ndombe.

The relationship between absolute fecundity and total weight (g) of *N. stewarti* was visualized in Fig. 10.

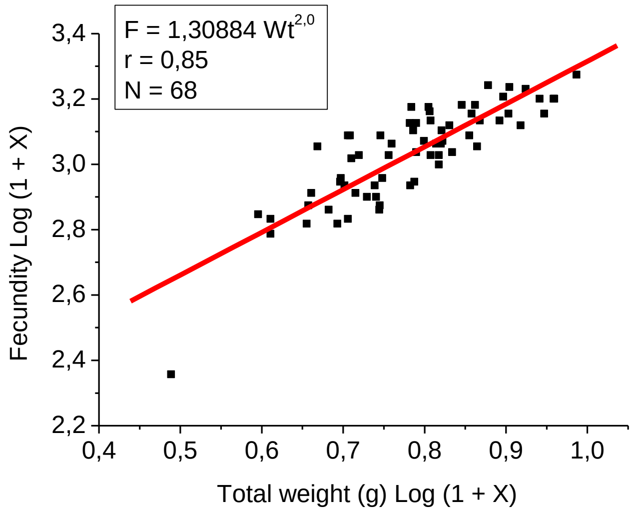


Figure 10. Absolute fecundity - total weight relationship in *N. stewarti* females caught in Lake Mai-Ndombe.