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REPRODUCTIVE STRATEGY OF *Oreochromis niloticus* IN THE MICRORESERVOIR: LA PALAPA, MORELOS, MEXICO

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Abstract: Tilapia (*Oreochromis niloticus*) is a species that is exploited on the La Palapa bordo in the state of Morelos, Mexico, with a size range for males between 15 and 25.5 cm in total length and for females of 9.2-20.8 cm in total length. The sex ratio favored males. The type of growth for this species is negative allometric (b<3). The size at first maturity for females is 17.2 cm and for males 16.8 cm. Clark's condition factor values showed that females present variability in the system, while males remain constant. Regarding the gonadosomatic index (IGS), hepatosomatic index (IHS) and stages of gonadal maturity, it can be observed that the species reproduces in two seasons of the year, from December to January (dry season) and from April to June (dry season). and beginning of rains). Mean fecundity was 718 oocytes/fish, with oocyte diameters between 300 and 3200 µm. Multivariate analysis of covariance (ANAMUCOVA) was performed, applying the criteria of García-Berthou and Moreno-Amich (1993). Physical and chemical parameters within the recommended range for organisms to have good growth and reproduction.
Keywords: Gonadal maturity, first sexual maturity, sex ratio, reproduction.

Reproduction in almost all animals is subject to different extrinsic variables (photoperiod, feeding, temperature, currents, response induced by the presence of the opposite sex and some other environmental factors) and intrinsic (genetic characteristics, metabolic and in a determined way the reproductive endocrine mechanism) that affect their behavior in each aquatic system (King, 2007; Makori *et al.* 2017).

In general, organisms must respond to changes in the environment and knowledge about reproductive aspects is very useful for understanding the basic biology of a resource, with fecundity and fertility being the factors that influence the abundance and recovery of a species. population (Granado, 2002; King, 2007).

Artificial reservoirs such as micro-reservoirs or bordos, in addition to being used in agricultural activities, are also used in aquaculture activities through the introduction of various freshwater species, among which the mojarra of African origin stands out:

Oreochromis niloticus, (Linnaeus, 1857), which have found favorable conditions that have allowed their introduction into different bodies of water throughout the national territory and worldwide (Bolívar *et al.*, 2004; El-Sayed, 2006; Quiroz and Díaz, 2010).

Tilapia has great importance in the production of animal protein in tropical and subtropical waters around the world, particularly in developing countries, being identified as the most relevant species for aquaculture (El-Sayed, 2006). The main attributes presented by tilapia are: fast growth, resistance to diseases, high productivity, tolerance to develop in high density conditions, ability to survive low oxygen concentrations and different salinities, as well as the ability to feed on a wide variety of sources. variety of natural and artificial foods (De Graaf *et al.*, 1999; Liti *et al*, 2005; El-Sayed, 2006; Ng & Romano, 2013).

Tilapia, since its introduction in Mexico, surpassed the capture of carp, coming to occupy the first place in the fishing production of the Mexican epicontinental waters and in 2017, 179,919 tons were obtained. For the state of Morelos, the production reported in the same year was 330 tons (CONAPESCA, 2019).

It is for the above that growth and reproduction as population parameters are of great interest in the analysis of the fishery, which together with other factors such as fertility, recruitment, growth, capture, etc. They will allow integrating predictive models on a given fishery resource (Granado, 2002; Yongo *et al.,* 2018).

The reproduction of tilapia is very well documented in other countries such as Africa and others around the world and few works have been carried out in different aquatic systems in the state of Morelos, Mexico. Studies on biological and commercial aspects of tilapia have been studied and published by: Fryer and Iles (1972), Babiker and Ibrahim (1979), Morales (1991), Gómez-Márquez *et al*. (1993), Admassu (1996), Siddiqui *et al*. (1998), by Graaf *et al*. (1999), Fawole and Arawomo (2000), Gómez-Márquez *et al*. (2003), Peña-Mendoza *et al*. (2005), Komolafe and Arawomo (2007), Gómez-Márquez *et al.* (2008) and Espinosa-Lemus *et al.,* (2009), Mashaiia *et al.* (2016), Yongo *et al*. (2018) and Mashaiia *et al.* (2022).

Therefore, it is important to carry out this type of study in Mexico, especially in the La Palapa aquatic system, Morelos, since there are no reports on this system so far, necessary for better management and exploitation of this species. Due to this, the objective of the study was to know the reproductive cycle of O. niloticus through morphophysiological indicators and its relationship with the physical and chemical factors of the water.

MATERIALS AND METHODS

The La Palapa bordo or microreservoir is located in the municipality of Ayala in the state of Morelos, between 18° 43'4.9" north latitude and 98° 54'39.7" west longitude, at 1220 m.a.s.l., in a warm sub-humid climate with rainfall in summer (Awo(w)(i'), average annual temperature of 25°C and rainfall between 800 and 900 mm (García, 2004).

Collections of 30 to 40 organisms were made monthly from September 2011 to August 2012, coming from the commercial capture with a net of 6.5 cm mesh size. The following biometry was performed on each specimen: total length (Lt), standard length (Lp) and height (A) with an ichthyometer and total weight (Pt) with a digital scale with a precision of 0.1 g.

Sex was determined by direct exposure of the gonads and the weight of the gonads (Pg), of the liver (Ph), of the digestive tract (Ptd), and the eviscerated weight (Pe) were obtained; the gonadal stage was recorded based on the maturity scale proposed by Peña-Mendoza *et al.* (2011).

At the same time, monthly water samples were taken at two stations at two depth levels (0.30 and 1.0 m), with a two-liter capacity Van Dorn bottle and stored in polyethylene bottles at a temperature of 4°C for its subsequent processing. Transparency and maximum depth were determined with the Secchi disk, water temperature and dissolved oxygen were recorded with a HANNA model HI9933 oximeter, pH and conductivity with a multiparameter (HANNA model HI 991300), alkalinity by the method of indicators, total hardness by the complexometric method and ammonium by the phenate method (Wetzel and Likens, 2000; APHA, AWWA and WPCF, 1999). Chlorophylls estimated by means of a spectrophotometer (Wetzel and Likens, 2000).

The total length and diameter of the gonads of females and males were recorded, in addition to the ovaries the oocytes were counted, as well as their measurement with the help of a stereoscope and the Motic Images Plus program ver. 2.0 (2005), to determine relative fertility (Salgado-Ugarte *et al.,* 2005) and mean fertility (Shoesmith, 1990).

The sex ratio was determined by means of the chi-square goodness-of-fit test (c2; p<0.05) with Yates correction, monthly and annually. The length (L)-weight (W) relationship was obtained by means of the following weight growth expression, $P = a L^b$ (Pauly, 1984), from which, if b=3, growth is isometric and if b ≠ 3 is allometric.

The size at first sexual maturity was obtained using the logistic method in which it represents the length at which 50% of all individuals are sexually mature (King, 2007). The condition factor (K) that indicates the welfare or robustness of the fish population, was obtained through the expression $K = Pe/Lt^b$, proposed by Clark (1928; cited in Nikolsky, 1963) which suggests the use of eviscerated weight (Pe).

The gonadosomatic index (IGS) was determined, which assumes that the ovary increases in size as development increases and compares the mass or weight of the gonad (Pg) with the mass or eviscerated weight of the animal (Pe) (Salgado *et al*, 2005; King, 2007). The hepatosomatic index (IHS), considers the relationship between the weight of the liver (Ph) and the weight of the eviscerated fish (Pe) and is specific for females, since the liver secretes exogenous vitellogenins that are going to be captured by the ovule Developing. It is directly proportional to the reproductive cycle and decays just before spawning.

The Multivariate Analysis of Covariance (ANAMUCOVA) was applied, which is a method proposed by García-Berthou and Moreno-Amich (1993), who propose that, instead of having a single response variable in the linear method, all the Measures related to reproductive activity are simultaneously included together with factors such as sex and sampling date and adjusted for the use of a covariate.

In order to know the behavior of the physical and chemical parameters, mainly at the time of reproduction, an exploratory data analysis was carried out and the non-parametric analysis (Mann-Whitney U and Kruskal-Wallis) was used because the data did not are considered normal and homoscedastic. Likewise, Spermman's correlation coefficient analysis was applied to relate biological variables and physical and chemical factors.

RESULTS

Physical and chemical parameters: The physical and chemical parameters of both stations were compared by means of the Mann-Whitney U analysis and these did not show a statistically significant difference between levels and neither between stations for each of the parameters (T water: W=270.5, p= 0.725777; Conductivity: W=260, p=0.570652; Dissolved Oxygen: W=265.5, p=0.650019; pH: W=275.5, p=0.804504; Total Hardness: W=263.5, p=0.620517; Total Alkalinity: W=321, p=0.485438; and ammonium: W=259, p=0.556629), which indicates that they behaved in a similar way. The Minimums, Maximums and Average values of each parameter can be seen in table 1.

Parameter	Minimum	Maximum	Average
Water temperature (°C)	22.2	28.8	24.7
Depth (m)	1.7	4.0	2.8
Transparency to the Secchi disk (m)	0.23	0.47	0.35
Dissolved oxygen (mg/l)	2.3	10.1	5.4
pH	7.8	8.5	8.1
Conductivity (μS/cm)	853	1488	1158
Total alkalinity (mg $CaCO_3$/l)	496	763	624
Total hardness (mg $CaCO_3$/l)	534	116	324
Ammonium (mg/l)	0.22	0.91	0.56
Chlorophyll a (mg/l)	7	90	65

Tabla 1. Recorded values of the physical, chemical and biological parameters in the water of the La Palapa embankment.

BIOLOGICAL PARAMETERS

A total of 384 organisms ranging from 15 to 25.5 cm in total length and 67.1 to 252.6 g in total weight for males were captured. In females, sizes ranged from 9.2 to 20.8 cm total length and 15 to 147.4 g total weight. (Table 2). A Mann-Whitney U analysis (W = -6850.0 p = 0.0) was performed, which showed that there are statistically differences between the lengths of females and males.

A size frequency distribution analysis was carried out where it was observed that most of the males were found between the size intervals of 18 to 20 cm in total length, while for females the interval ranged between 16 and 18 cm in length. overall (Figure 2).

Of the 384 organisms captured, 79.7% corresponded to males (306) and 20.3% were females (78); the male: female sex ratio was 3.9:1 (c2= 135.38; $p < 0.05$); favoring males.

	Males			Females		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Total length (cm)	15	25.5	19.3	9.2	20.8	17
Pattern Length (cm)	9.3	20	15.2	7.1	16.8	13.7
Height (cm)	4.5	8.6	6	4	6.4	5.2
Total weight (g)	67.1	252.6	124.5	15	147.4	89.4

Table 2. Summary of biometrics for males and females of *O. niloticus.*

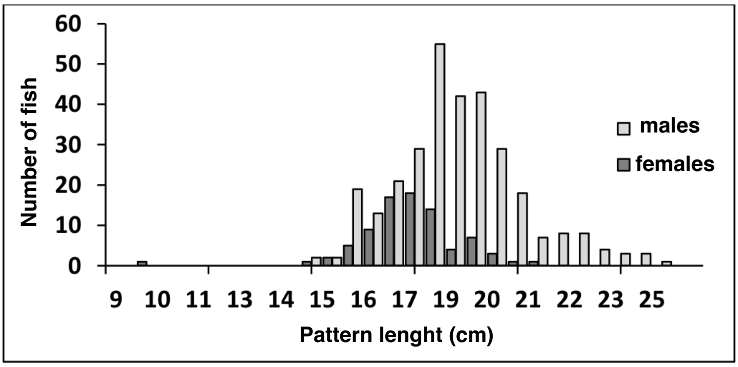


Figure 2. Length frequency distribution for females and males of *O. niloticus.*

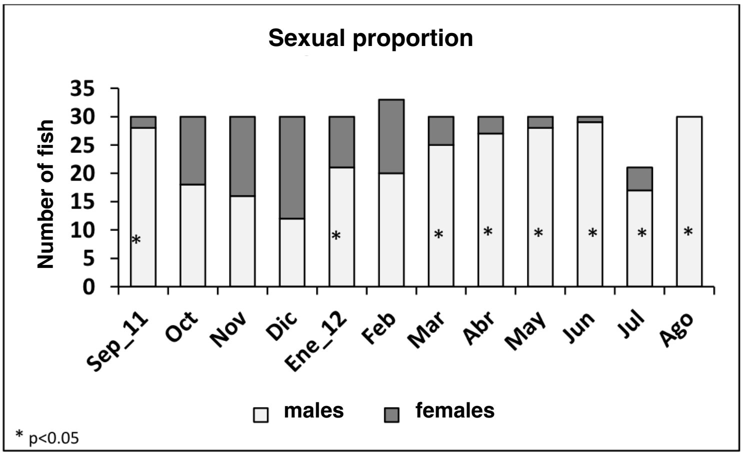


Figure 3. Monthly variation of the male and female sex ratio of *O. niloticus.*

Figure 3 shows that the highest number of females was recorded from October to December, while the highest number of males was recorded in September, June and August. In some months no statistically significant differences in sex ratio were detected.

In order to know the relationship between the size of the organisms, a regression was performed between the standard length and the total length (Figure 4). It was obtained that for the population of O. niloticus, there is a linear relationship with a high correlation (r=0.932) between these variables. The purpose of this relationship is to be able to transform both variables (Lt or Lp) for purposes of comparison with other studies.

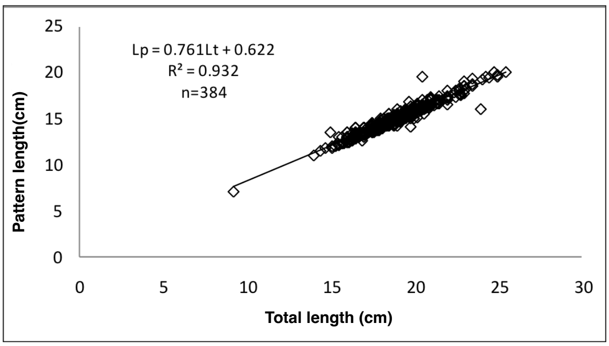


Figure 4. Linear relationship between total length-pattern length for *O. niloticus.*

The analysis of covariance (ANDECOVA) was applied to determine if there were differences between height and weight by sex. According to the values obtained, it was observed that there are significant differences ($F=9.91$: $p<0.005$) between the variables, so the linear regression was calculated for each sex.

The relationship standard length and total weight is observed in Figures 5 and 6, in which it is shown that for the total data (population) as well as for both sexes, a potential type behavior is presented; In addition, it can be seen that the males (Figure 6) are greater in weight and length than the females.

The t-Student test (Pauly, 1984) was applied to the slope values of each of the regressions and it was found that the slopes were different from three ($b\neq3$); (females, t-Student = 7.9; $p<0.05$ and males t-Student =17.6; $p<0.05$), which means that the type of growth for the population and both sexes is negative allometric; that is, organisms grow more in length than in weight.

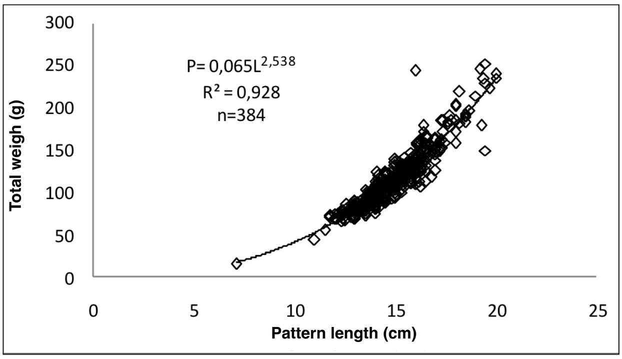


Figure 5. Rootstock length-total weight ratio for the population:*O. niloticus.*

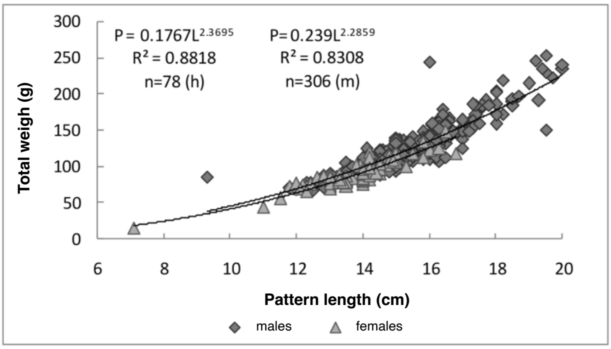


Figure 6. Relation of standard length-total weight for each of the sexes of *O. niloticus.*

Clark's condition factor for *O. niloticus* males showed a stable and constant behavior throughout the study, obtaining a drop in April and then increasing to remain constant (Figure 7) and following the behavior of temperature. of the water.

For females, variability can be observed, although they present a good condition, registering high values in the dry and rainy seasons and low values during the cold season, with the highest value in September (Figure

7). All condition values for females were lower than those for males.

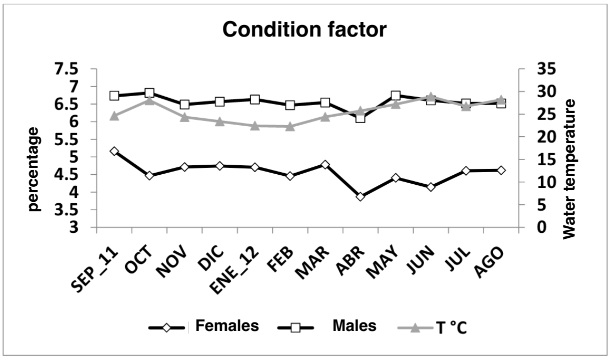


Figure 7. Comportamiento temporal del factor de condición para machos de *O. niloticus*.

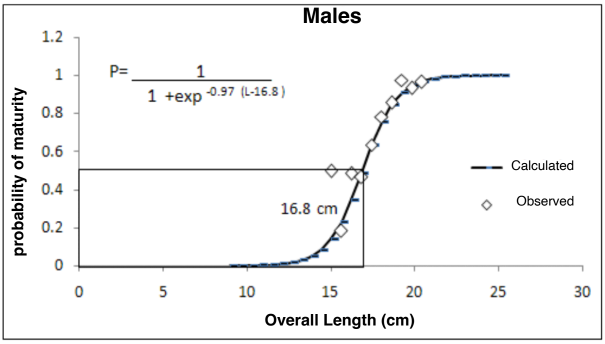


Figure 8. Size at first sexual maturity for males of *O. niloticus*.

Regarding the size of first sexual maturity at which the fish have the capacity to initiate the reproduction process, it was recorded that the smallest mature female was 13.4 cm in length and the smallest and most mature male was 14.3 cm. full length. The average size at first sexual maturity for O. niloticus males was 16.8 cm (Figure 8), while for females it was 17.2 cm. Apparently the males are precocious, as they mature a little earlier than the females.

To determine the reproductive season, the variation of the gonadosomatic index (IGS) as well as the values of the hepatosomatic index (IHS) of the females were analyzed. The results showed some variations throughout the study as observed in the IGS of females and males, showing that the small values were due to the fact that spawning has taken place and the fish is in a resting state. With the IGS values of the females, two breeding periods can be seen, a short one from July to September and a longer one from February to May with maxima in April (Figure 9).

Likewise, it can be seen that the reproductive period for males corresponds from April to June, which overlaps with that of females and another of lesser intensity in December.

Figure 9 also shows the variation of the average values of the IHS of females, in which it can be seen that the behavior of this variable is inverse to the IGS of females, since in April the minimum of IHS corresponds to a maximum of the IGS, although females were not well represented throughout the study.

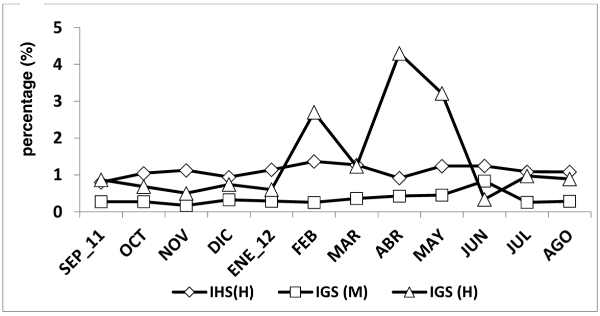
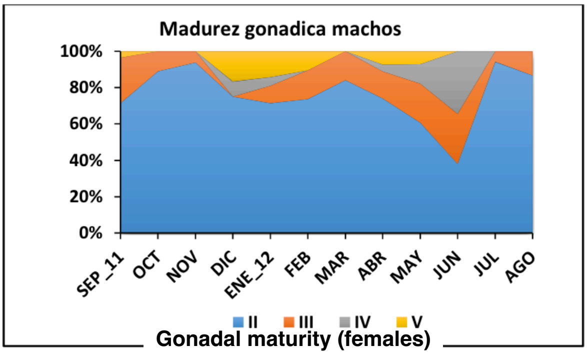


Figure 9. Temporal variation of the biological indicators of the reproductive condition of *O. niloticus*.

For the analysis of gonadal maturation of *O. niloticus*, it was recorded that most of the stages were present throughout the study except for the immature or undifferentiated stage (I). In Figure 10, according to the maturation scale, it can be observed for females that the stage with the highest proportion recorded is the development phase (II) with 70%, in the maturation phase (III) on 13 %, in the reproduction phase (IV) 15% and in the post-spawning phase (V) 3%; reproduction for females was observed in two periods, a short one from November to December and a long one from February to May. For males, the stage that dominated during the study was the developing stage (II) with 70%, the maturation stage (III) with 14%, the reproductive stage (IV) with 5% and the post-spawning stage (V) with 5%. ; it is also observed that the reproductive stage (IV) occurs in November-December and another in May-July.

Gonadal maturity (males)



Gonadal maturity (females)

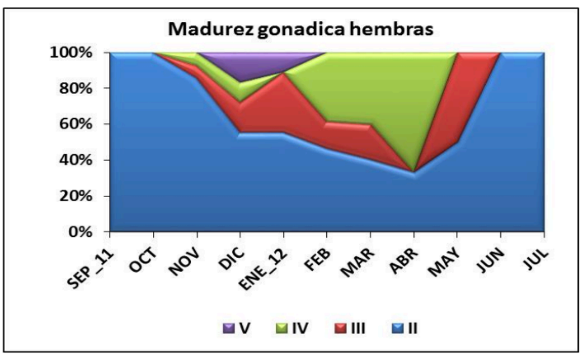


Figure 10. Temporal variation of the gonadal stages of males and females for *O. niloticus.*

Regarding the length and diameter of the ovaries, it was observed that the maximum length (4.5 cm) was obtained in September and the minimum in October (0.9 cm), while for the diameter the highest value was in February (1.1 cm) and the minimum in October (0.1 cm); Regarding weight, the lowest was recorded in October (0.1 g) and the highest in April (3.9 g) corresponding to maturity stage IV. For the lengths of the testicles, the highest values of length (5.76 cm) and the minimum values in the months of September and October (1.2 cm) were obtained in the months of September and April; for diameters, the minimum value was measured in September (1.1cm) and the highest value in April (5.8), in terms of weight these ranged from 0.1g in January to 2.3g in April.

The fecundity of *O. niloticus* in the La Palapa embankment varied in each stage, in the development stage (II) there was an interval of 250 to 550 oocytes with an average of 436 and a diameter of 300 to 2000 µm, in females that they had an average length of 16.8 cm and a weight of 86.8 g; in the maturation stage (III) 483 to 868 oocytes were counted with an average of 769, diameter from 400 to 3100 µm, in females with an average length of 17.2 cm and weight of 93.1 g and in the reproduction stage (IV), recorded from 455 to 842 oocytes with an average of 735, diameter from 500 to 3200 µm, in females with an average length of 18 cm and 100 g.

Figure 11 shows the correlation between fecundity (number of ovules) and the standard length of the fish, which was greater (r2=0.724) than the correlation with the total weight (r2= 0.6485), indicating a potential relationship of the allometric type, in which it is observed that fecundity increased with the increase in body length. The average fertility obtained for *O. niloticus* was 718 oocytes per fish.

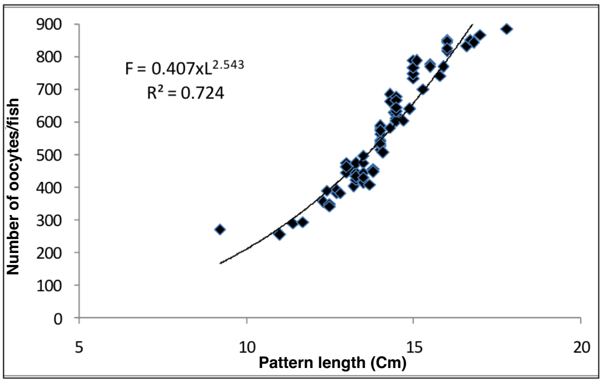


Figure 11. Variation of standard length and fecundity (number of oocytes) for *O. niloticus.*

Although the reproduction indicators (IGS and IHS) represent the behavior of the information for the species, the values of the adjusted means of total weight, eviscerated weight, gonad weight, liver weight and digestive tract weight were obtained with the analysis covariance multivariate analysis (ANAMUCOVA), in order to support the trends observed with the reproduction indicators.

The multivariate analysis of covariance for females shows a significance value for most of the variables with the exception of liver weight, which is not significant according to the Pillai, Wilk, Hotelling and Roy criteria ($p<0.05$); all others were significant. For males, it shows a significant value for all variables according to the Pillai, Wilk, Hotelling and Roy criteria.

The results obtained for the means adjusted by the covariate (pattern length) for the females are shown in Figure 12, in which it is observed that for the weight of the gonad there are two maximums that indicate the breeding season of the species, one small in September (rainy season) and a more pronounced one from February to May (dry season). Regarding the weight of the liver, this shows an inverse behavior to that of the weight of the gonad; the total weight and the eviscerated weight have a similar constant behavior with a decrease in the month of April during the reproduction period; the weight of the digestive tract is constant with an increase in November and June after the reproductive period, these being the months in which the weight of the gonad is the lowest throughout the study.

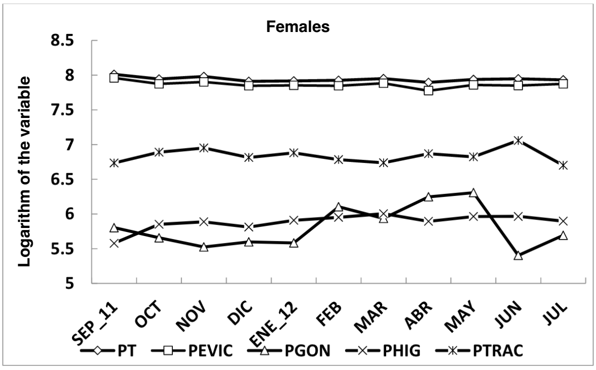


Figure 12. Adjusted mean values per month predicted by the effect of the covariate (length) in the sample for females of *O. niloticus.*

Regarding the adjusted means for males, these present a constant behavior in all the variables. In the weight of the gonad, like the females, it presents two reproduction maxima, one less pronounced in October and one higher in June; liver weight does not show an inverse behavior as in the case of females, it remains constant with a small increase in November. As far as the total weight and the eviscerated weight are similar and almost constant, denoting a good condition of the organisms after the reproductive period, although during the months of April and October the condition decreases slightly to later increase in the reproduction period; the weight of the digestive tract shows a small increase in November and a decrease in June where an increase in the weight of the gonad can be observed (Figure 13). What was found in the ANAMUCOVA analysis is very similar to what was obtained in the stages of gonadal maturity and in the reproductive indicators (IGS and IHS) for both sexes.

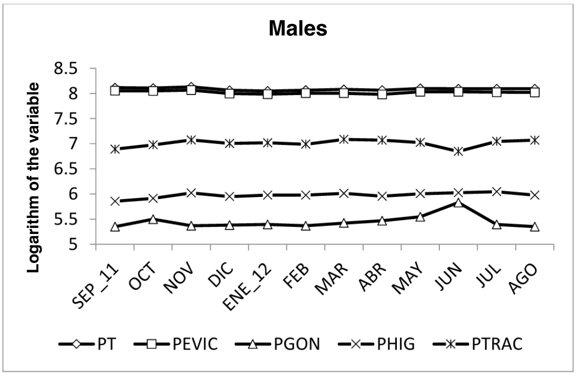


Figure 13. Adjusted mean values per month predicted by the effect of the covariate (length) in the sample for males of *O. niloticus.*

A logarithmic regression analysis was performed between the values of the gonadosomatic and hepatosomatic index with the physical and chemical factors and only a couple of variables were obtained that have a significant directly proportional relationship, which were IHS and pH ($r=0.7014$; $p<0.05$) and between the temperature of the water and the IGS of the males ($r=0.5956$; $p<0.05$). The other correlations between the variables were not significant or the association values were very low.

DISCUSSION

PHYSICAL AND CHEMICAL PARAMETERS

The quality of the water is determined by its physical and chemical properties, which influence the production and reproduction of the fish, so it is important that the water parameters are maintained within the optimal intervals for the development of the organisms.

The bordo "La palapa" is a shallow body of water with a depth of 1 m in the dry season and up to 4 m in the rainy season, with a transparency of 0.47 m. The hydrological behavior of the system is characterized by a stage of dilution, due to the increase in volume from the beginning of the rains (June), in which the hauling of materials from the basin occurs, and another stage of concentration of materials, caused by evaporation during the dry season, infiltration, and loss due to the use of water for irrigation, which are described by Quiróz and Díaz (2010) and Gómez-Márquez *et al.* (2013).

This system is favored by the action of the wind and by fishing activity, since it presents a constant removal of materials and nutrients from the bottom and, therefore, less transparency. The turbidity of the water due to suspended organic and inorganic materials has two types of effects: one, by preventing the free penetration of solar rays, the suspended solids limit the natural productivity of the shore, which in turn reduces the availability of food for *Oreochromis* (Alamilla, 2009), and also affects the respiratory processes of organisms by covering the gills and preventing gas exchange (Iturra, 2008).

The water temperature indicates that it is a warm water system, suitable for reproduction (22 to 28°C) as reported by Fryer and Iles (1972), Morales (1991), Gómez-Márquez *et al.* (2003) and Manríquez (2005), who mention that the spawning temperature is higher than 20°C and below this, reproduction is inhibited (Arredondo and Ponce, 1998).

The aquatic system presents good oxygenation for the development of tilapia, since it can withstand low dissolved oxygen concentrations of up to 1 mg/l as mentioned by Arredondo and Ponce (1998) and Morales (1991). On bordo, values between 2 mg/L in September and 10 mg/L in January were recorded.

The pH values of the water are optimal for the growth and reproduction of fish, as cited by Arredondo and Ponce (1998), Morales (1991) and Njiru *et al.* (2006), with a recommended range of pH between 6 and 9 units, and hardness greater than 200 mg $CaCO_3$/l like that of the bordo, which tend to be more biologically productive than soft waters (<40mg $CaCO_3$/l), since the latter are deficient in calcium and magnesium and affect fertility (Goldman and Horne, 1983) and to provide adequate segregation of mucus in the skin (Arredondo and Ponce, 1998).

Chlorophyll a is an indicator of phytoplankton biomass, of the degree of eutrophication of aquatic ecosystems and of the physiological state of phytoplankton (Goldman and Horne, 1983). Pena-Mendoza *et al.* (2005), mention that when the phytoplankton biomass increases, the IGS also increases in the Emiliano Zapata dam, which is due to the high concentration of nutrients and the mixing of the water column due to the effect of rain.

Regarding the height and weight of *O niloticus* obtained in the present study, similar values were reported by Abdulrahaman (1996-1997), Gómez- Márquez *et al.* (2003), Gómez-Márquez *et al.,* (2008) and Sastré (2008). Contrary to this study, Mashaii *et al.* (2016) and Yongo *et al.* (2018), mention values of higher sizes and weights, mainly for males, a strategy used for reproduction, because for males to be accepted by females they must be large, bright and striking in color so that their genes are transferred to their offspring and therefore survival is greater.

For the sex ratio of *O. niloticus* Peña-Mendoza *et al.* (2005), Gómez-Márquez *et al.* (2008) Njiru *et al.* (2006), Yongo *et al.* (2018) and Ramos-Cruz (1995) for O. aureus, recorded a proportion similar to that reported for this study, in which males dominated. Arul (2000) reports that females favored the ratio in his study. It is possible that once the fertilization of the ovules is completed, the females migrate to deep waters or to areas near the shore where there is aquatic vegetation or rocks to protect themselves and carry out the incubation of the eggs and care for the young. On the other hand, the males remain in the shallow areas where the nests are located to court another female and that is where they are captured by the type of fishing gear used (Ramos-Cruz, 1995; Gómez-Márquez *et al.,* 2003).

Also, the fact that at some time the catch is made up of more males may be favorable for the fishery and the size of males may be the result of a differential growth rate with respect to females. Regarding sexual differentiation, Van Guerrero-Estévez and Moreno-Mendoza (2009) point out that there is a wide variety of mechanisms that define and influence sexual proportion; these can be genetic or depend on environmental conditions such as temperature, pH and factors inherent in the community.

The length-weight relationship shows that all organisms have negative allometric growth; that is, they grow more in length than in weight. Similar results have been reported by Gómez-Márquez *et al.,* (2008) and Sastre (2008) and Yongo *et al.,* (2018) only for males. Instead, Njiru *et al.* (2006) and Yongo *et al.* (2018) mention that the population of *O. niloticus* presents a positive allometric growth (greater growth in weight than in size), similar to that cited by Beltrán-Álvarez (2010) but for *O. aureus* at the Sanalona dam in Sinaloa. This negative allometry strategy works to avoid predation and later, as they grow, they show positive allometry, due in part to the reproductive process as the gonads increase in weight and size and because they accumulate more tissue.

The condition index is an indicator of well-being or robustness of a fish population, which serves as a basis for inferring changes in the condition of organisms as size, age and seasonal variations increase before and after spawning (Nikolsky, 1963; King, 2007). In this study, males present higher values than females, which indicates that their condition is good and they will have more energy, which they will spend searching for their mate and later protecting the nest; however, a small decrease is observed as the reproductive cycle progresses. On the other hand, the females show well-marked differences, which is where it indicates that the reproduction has passed and they have wear and tear due to the care of the young. Values different from those observed in this study are reported by Yongo *et al.* (2018).

The size at first sexual maturity for this study is similar to that recorded by Gómez-Márquez *et al.* (2003) but lower than that reported by Yongo *et al.* (2018) and Mashaii *et al.* (2016). The study of sexual maturity constitutes a first contribution to the knowledge of the basic biology and the reproductive cycle of O. niloticus.

Morales (1991), Admassu (1996), and Mashaii *et al.* (2022), report that females spawn more than once a year and that spawning frequency varies considerably depending on environmental factors. The IGS variations indicate that the reproduction of the species takes place throughout the year, with a period of greater reproductive intensity, as observed for the species on the La Palapa embankment.

Numerous experimental studies show that temperature is one of the main environmental factors that regulate this cycle, although light also plays an important role, as well as the salinity of the water, the concentration of ammonia, noise, etc. (De Juan *et al.,* 2009).

The fecundity or reproductive potential of Nile tilapia has been documented by different authors. Njiru *et al.* (2006), mention values between 905 to 7,619 ovules in fish with a total length of 28 to 51 cm and De Graaf *et al.* (1999) in farmed tilapia reports data between less than 100 to 3,000. Peña-Mendoza *et al.* (2005) and Mashaii et al (2016) cite values similar to those recorded in this study (243 to 847 ovules), which is considered low fertility. King (2007) points out that the relationship between the number of ovules and size, age or weight tends to decrease as organisms get older, for which it is necessary to also analyze their size.

Oocyte diameter has been reported to vary between 1000 and 3000 μm by De Graaf *et al.* (1999), Gómez-Márquez *et al.* (2003); Mashaii *et al.* (2016) and Mashaii *et al.* (2022), similar to the data obtained in this study. Coward and Bromage (2000) point out that the age of the broodstock is the important factor influencing the size of the ovules. Duponchellea *et al.* (2000) mention that farmed tilapias produce smaller ovules than those found in the wild.

When the multivariate analysis of covariance was applied, the results obtained for females and males follow the same trend, which suggests that the behavior of the average weight of the variables, especially of the gonads, presents a marked seasonal variation. Salgado-Ugarte *et al.* (2005), cites that the use of multivariate analysis of covariance has some advantages.

For example, a preliminary analysis of the gonadosomatic index shows a clear heteroscedasticity which makes comparisons difficult and, on the other hand, the comparison of the adjacent mean values allowed evaluating the significance of the variation of the means throughout the different periods in study.

Although, in this study, slightly different results were obtained from those reported in the background, this is mainly due to the intensity of exploitation (number of fishermen, fishing days, catch quotas, etc.) to which the fish is subjected. species, as well as the morphometric characteristics and the lack of a management and administration program by the Cooperative Society, which would allow it to obtain better economic income and greater reproductive potential for long-term sustainability purposes.

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