Maturity size and fecundity of hybrid tilapia *Oreochromis aureus X Oreochromis niloticus* (Perciformes: Cichlidae) from the reservoir Fernando Hiriart Balderrama "Zimapan", Hidalgo, Mexico

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ABSTRACT: Maturity size and fecundity of hybrid tilapia *Oreochromis aureus X Oreochromis niloticus.* (Pisces: Cichlidae) from the reservoir Fernando Hiriart Balderrama "Zimapan", Hidalgo, Mexico were determined in organisms caught between 2007 and 2008. A total of 506 hybrid fishes were captured and showed a range of sizes from 20 to 28,9 cm standard length (S_L), and total weight of 200 to 750g (T_w). The estimated maturation size for females was 20,8cm and 22cm for males, respectively. Fecundity was estimated on 50 gonads and a mean of 3 113±1 826 eggs was recorded per gravid female. Based on these results, these fishes are suitable for commercial exploitation and imply good conservation in correlation to the regulatory strategies for fisheries established in the area, at least from a reproductive point of view.

Key words: sexual ratio, hybrid, fecundity, gonadic maturity, condition factor.

RESUMEN: La biología reproductiva de la tilapia hibrida *Oreochromis aureus X Oreochromis niloticus* en la presa Zimapán fue analizada en organismos colectados entre 2007 y 2008. Un total de 502 peces fueron capturados y mostraron un intervalo de tallas que varió de 20 a 28,9 cm de longitud standard (S_L) y un peso total de 200 a 750g (T_w). Los especímenes mostraron una tasa de crecimiento isométrico. La talla estimada de madurez en hembras fue de 20,8cm y 22cm para machos, respectivamente. La fecundidad se estimó en una muestra de 50 gónadas y se obtuvo un promedio de 3 113±1 826 huevos por hembra grávida. Basados en estos resultados, estos peces son susceptibles de explotación comercial y muestran cierto estado de conservación como recurso pesquero, probablemente como resultado de las estrategias regulatorias de pesquerías existentes en el área, al menos desde la perspectiva reproductiva.

Palabras claves: proporción sexual, híbrido, fecundidad, madurez gonadal, factor de condición.

Cichlids are distributed worldwide, their origin is in Africa and Madagascar but they have been introduced in to many tropical and subtropical countries, including those of Central and South America (Fryer & Iles, 1972; Morales, 1991). In 1976, *Oreochromis niloticus* (Lineaus, 1758), Nile Tilapia, was introduced in to Mexico after a previous introduction in Panama (Arredondo-Figueroa & Tejeda-Salinas, 1989). Tilapia is one of the three most important freshwater fisheries in Mexico; the annual production of Tilapia in 2008 was 71 312 tonnes representing about 48,31 % of the country's total inland fishery production (SAGARPA, 2008). Scientific investigation of the natural resources present in Mexican reservoirs have mainly focused on the capacity for their commercial exploitation as a fishery resource, due to their social and economic importance, however, some biological aspects such as reproductive condition or conservation status are poorly understood and studied (López-Hernández, Ramos, Gómez-Ponce, Figueroa-Torres & Carranza-Fraser, 2007). The Zimapan reservoir has an area of 22,9km^2 and is located on the boundary of the states of Queretaro and Hidalgo, between the watersheds of the Tula and

San Juan rivers. Commercial exploitation of the fishery began in 1998. Due to social and economic pressure present in this region, fishing has become a key source of income for local communities (Hernández-Montaño & Orbe-Mendoza, 2002). Currently, residents of coastal communities on both shores of the reservoir (Queretaro and Hidalgo States) have a strong interest in fishing, with captures mainly represented by Tilapia (*Oreochromis* spp. Günther, 1889), while Common carp (*Cyprinus carpio speculari,* Linnaeus 1758) and Largemouth bass (*Micropterus salmoides salmoides* (Lacepède, 1802)) are caught incidentally.

Some more recent studies have been focused on fishery aspects of tilapia in Zimapan (Arellano-Torres, Hernández & Melendez, 2013; Gómez-Ponce, Granados-Flores, Padilla, López-Hernández & Núñez-Nogueira, 2011; Hernández-Montaño & Meléndez-Galicia, 2010; Hernández-Montaño & Orbe-Mendoza, 2002; López-Hernández et al., 2007; Hernández-Montaño & Orbe-Mendoza, 1999) and other fishes (Bermúdez, 2007; Hernández-Montaño & Orbe-Mendoza, 1999), but very few on its reproduction (Hernández-Montaño & Meléndez-Galicia, 2010; Hernández-Montaño & Orbe-Mendoza, 2002). These studies have been important for sustainable management strategies established of this resource in the reservoir. Fish closed season has been establishes from April 25 to June 20 as a regulatory strategy for conservation of local Tilapia fisheries (SAGARPA, 2013), considering minimum catch size for commercial porpoises of 23,0cm standard length (DOF, 2007; Hernández-Montaño & Meléndez-Galicia, 2010). This study analyzed the reproductive biology of hybrid tilapia (*Oreochromis* aureus *x Oreochromis niloticus*.) specifically the reproductive length at first maturity, sex ratio and fecundity, providing a baseline for future studies, and its implication on local fishery conservation respect of regulatory strategies established for the Zimapan reservoir.

MATERIALS AND METHODS

This study was carried out in the Zimapan reservoir which is located on the boundary between the states of Queretaro and Hidalgo (20°38'50.90"N and 99°29'19.90"W). Samples from the commercial catch were taken in several localities (El Rito, Manguani, Tzibanza, La Cortina, El Epazote, Noxthey y La Florida) at approximately monthly intervals from May 2007 to April 2008. Fish were caught by static commercial gill nets of 4,5inches, with a maximum length of 60m, height of 5m and an aperture of 11,43cm, as a part of an age-growth study (Gómez-Ponce et al., 2011).

The nets were placed in the late afternoon and collected the next morning. The organisms were identified using dichotomous keys (Trewavas, 1983; Arredondo-Figueroa & Guzmán-Arroyo, 1986). All the specimens caught and analyzed showed features of hybridization as was established previously (Gómez-Ponce et al., 2011). For each fish, the standard length (S_L) was obtained by measuring from the tip of the snout to the base of the caudal peduncle. Total length is not reported as several fishes had damaged or bitten caudal fins. For the registration of the standard length we used a graded ruler of 50cm with 1mm accuracy. Total weight (T_w) was expressed in grams and weighed with a scale (OHAUS™ 10 kg) with an interval of 0.1 grams of precision. Fishes were separated by sex and the sex ratio was recorded by date of collection.

The size at first maturity was determined when height at which 50% of the cumulative relative frequency of specimens were in ripe stage (phase IV) of the maturity scale of Nikolsky (1963). To calculate the size at first maturity the data were fitted to logistic models (Sparre & Venema, 1997) as follows:

$$Pi = \frac{1}{1 + e^{a-bSL}}$$

Where *Pi* is the proportion of mature fish defined by length interval and *a* and *b* are model parameters. Once fitted, the size at first maturity (the length at which 50% of the fish are reproducing, *Lm*50%) was calculated as *Lm* 50% = *a* / *b*.

For fecundity determination, 50 gonads were randomly selected and a subsample of 1 g dissected for egg counting, assisted by a stereoscopic microscope (Leica™). The fecundity was estimated using the total number of eggs (Total Fecundity) contained in the ovary of the fish. The gonadosomatic index (GSI) for each fish was calculated based on the weight, expressed as percentage (de Vlaming, Grossman & Chapman, 1982). The monthly frequency of the various maturity stages determinate using the table proposed by Nikolski (1963) was plotted, and mean females fish (248) were used for fecundity estimations.

A correlation analysis was performed between the number of eggs and standard length (S_L), and between number of eggs and total weight (T_w).

RESULTS

Based on the main anatomical features considered for taxonomical identification (Trewavas, 1983, Arredondo-Figueroa & Guzmán-Arroyo, 1986) the Tilapias from Zimapan reservoir share features from two of the originally introduced species (*Oreochromis niloticus* (Linnaeus, 1758) and *Oreochromis aureus* (Steindachner, 1864)) (Table 1). In this study all organisms were considered as hybrids (*Oreochromis niloticus x Oreochromis aureus;* Gómez-Ponce et al., 2011).

A total of 506 fishes ranging from 20 to 28,9cm in standard length (S_L), and 200 to 750g in body weight, with a sex ratio of 1,06 comprised of 262 females (51,8 %) and 243 males (48,2 %) were captured. The most common size range was 21 to 25cm of S_L and a total weight of 350 to 500g (Figs. 1-2). Females were more numerous from April to September and the males from January to March (Table 2). The sex ratio was 1:1.06 (females:males) and did not differ significantly of the expected ratio 1:1 (x^2=0,02; P=0,05).

TABLE 1
Summary of diagnostic morphological features considered in identifying specimens of Tilapia from Zimapan Dam.

Features	Species		
	Oreochromis niloticus	*Oreochromis aureus*	Fishes from Zimapan dam
Gill rakers number[1]	18 – 28	18 – 26	23 – 29
Scales number on lateral line[1]	30 – 34	30 – 33	33 – 36
Dorsal fin (modal formula) [1]	XV – XVIII (13)	XIV – XVII (12 – 15)	XVI – XVII (13)
Anal fin (modal formula) [1]	III (10 –11)	III (9 – 11)	III (8 – 10)
Features of pharyngeal bone[2]	Area toothed with irregular density.	Upper lobes well marked. Dentate area with low density.	Upper lobes and superior bone nearly straight or very poorly developed.
Features of pharyngeal teeth bone[2]	Bicuspid teeth in the upper and monocuspids curved backwards at the bottom.	Fine and thin monocuspids teeth.	Presence mostly monocuspids teeth with very little presence of bicuspid teeth.
Presence of regular vertical and well defined stripes in the caudal fin[1]	Present	No present	Present

[1] Trewavas (1983).
[2] Arredondo-Figueroa &Tejeda-Salinas (1989).

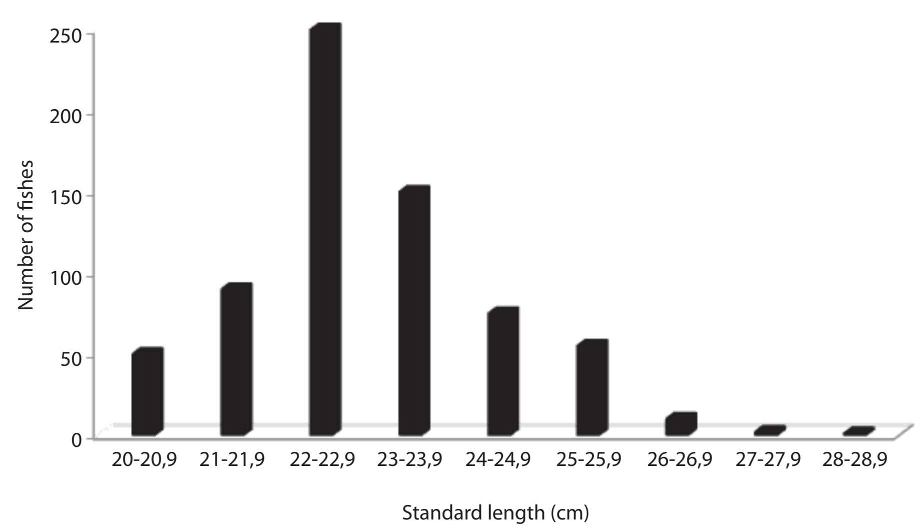

Fig. 1. Quantity of tilapia *Oreochromis aureus* x *Orechromis niloticus* by standard length (cm).

SIZE AT FIRST MATURITY

Based on the logistic model proposed by Sparre & Venema (1997), the reproductive maturity length was obtained. In the case of females (Fig., 3), the estimated length was 20,8cm. In the case of males it was 22,2m (Fig. 4).

The fecundity ranged from 255 to 6 930 eggs per female, with an estimated mean fecundity of 3 133±1 826 (±S.D.). Mature gonads corresponded to organisms between 20,0 and 25,9 cm S_L and 200 to 750g T_w. The minimum size recorded with mature gonads was 20,0cm S_L and 200g of T_w and maximum of 25,9cm S_L and 400g T_W. A significant relationship was found between S_L and fecundity (R=0,870; P<0,05). There was a relationship between fecundity and T_W (R=0,806; P<0,05) as well. Higher fecundity value was observed in females between 21 and 25cm S_L, and between 400 and 800g total weight (Figs. 5-6).

Gonadosomatic Index: The monthly gonadosomatic index showed two peaks, one during May and the second in November in both sexes (Fig. 7).

Percentage of each gonadal development stage is illustrated in figures 8 and 9. According to females gonadic

TABLE 2
Sexual distribution of (*Oreochromis aureus x Oreochromis niloticus*) by month.

Month	Females	Males	Total	X^2	*p-value*
January	16	25	41	3,240	ns
February	15	20	35	1,250	ns
March	12	25	37	6,760	*
April	27	20	47	2,450	ns
May	29	27	56	0,148	ns
June	30	29	59	0,034	ns
July	25	20	45	1,250	ns
August	23	18	41	1,389	ns
September	28	20	48	3,200	ns
October	25	17	42	3,765	ns
November	17	12	29	2,083	ns
December	15	10	25	2,500	ns
Total	262	243	505	0.803	ns

* Values significant at p <0,05; ns = no significant.

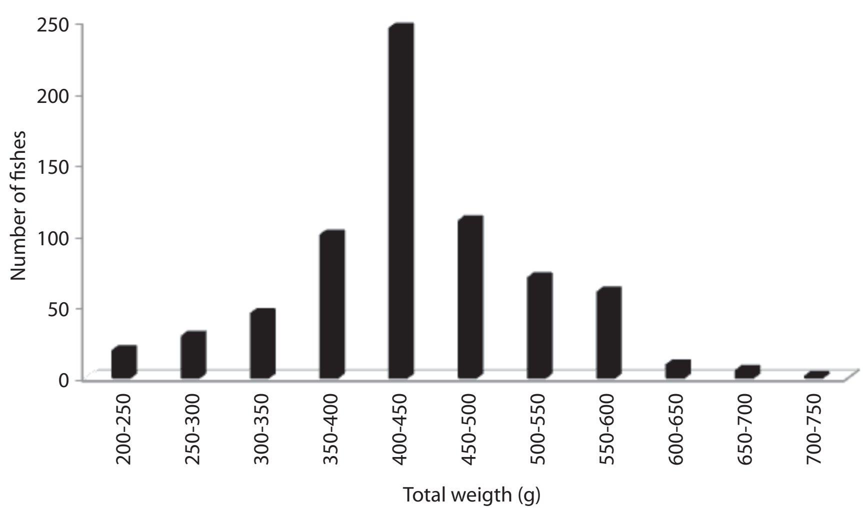

Fig. 2. Quantity of tilapia *Oreochromis aureus* x *Orechromis niloticus* by weight (g).

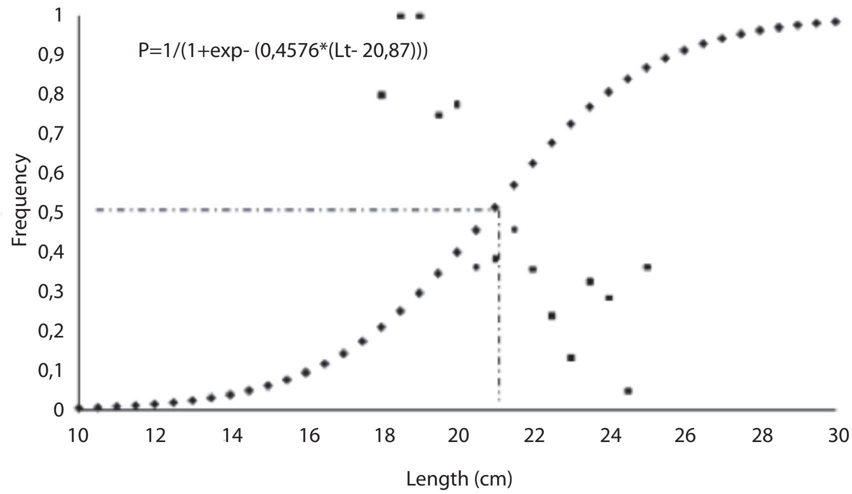

Fig. 3. Sexual maturity in Tilapia females (*Oreochromis aureus x Oreochromis niloticus*) from Zimapan reservoir.

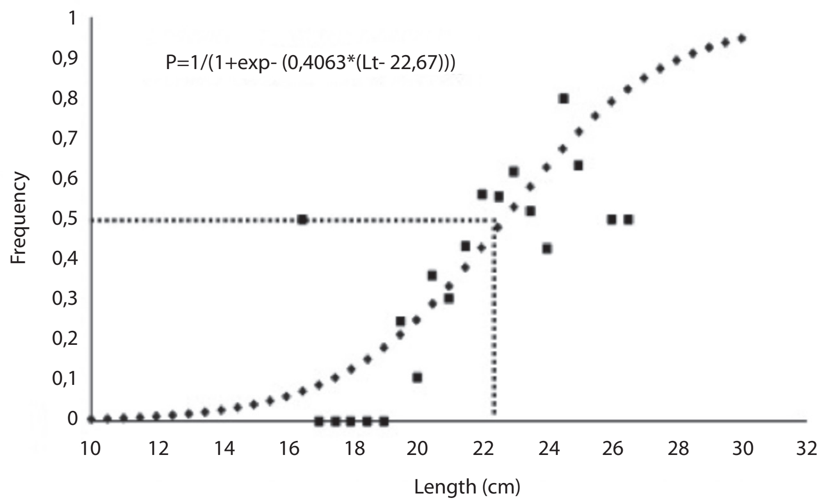

Fig. 4. Sexual maturity in Tilapia males (*Oreochromis aureus x Oreochromis niloticus*) from Zimapan reservoir.

maturation stages, 26,56% of the total fishes were maturing (II), 38,13% were mature (III) and 10,94% were ripe (IV) (Fig. 8). Therefore, 64,69% of the fish were in the reproductive process. In the males, 31,68% of the total fishes were maturing (II), 35,8% were mature (III), and 19,75 % were ripe (IV) (Fig. 9). Therefore, 67,48% of the fishes were in the reproductive process. The highest proportion of average gonadal ripe stage (IV) in females was found in June and January (Fig. 2). However, from April-May and November there was a reproductive season.

The condition factor in both males and females was greater than 1 indicating that both are robust, and both showed similar variation patterns by month (Fig. 10). Males had the highest condition factor (2,5). In both cases the highest values occurred in May and November (Fig. 10).

DISCUSSION

Reports on the hybridization capacity of Tilapia in the literature have been divided into three categories: 1) field observations on disturbed populations; 2) genetic studies of reproductive behavior; and 3) as tools to increase

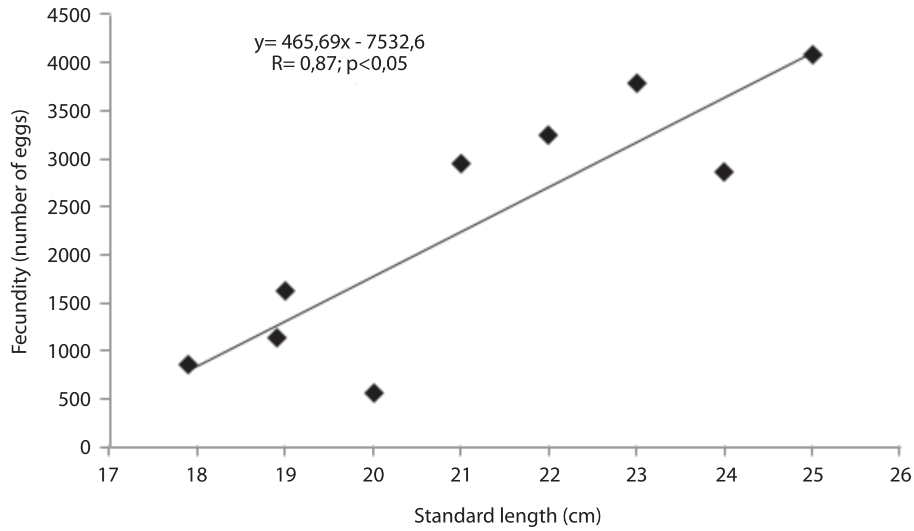

Fig. 5. Fecundity (number of eggs) and its relationship with length of the tilapia (*Oreochromis aureus x Oreochromis niloticus*).

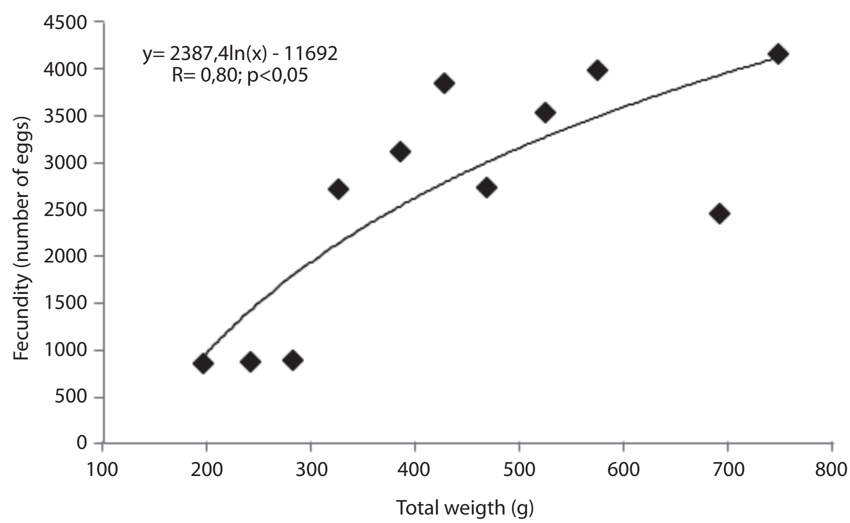

Fig. 6. Relationship between fecundity (number of eggs) and total weight of the tilapia hybrid (*Oreochromis aureus x Oreochromis niloticus*).

aquaculture production. Hybridization has been documented by several different authors (Trewavas, 1983; Wohlfart, Moav & Hulata, 1983; Pérez, Muñoz, Huaquin & Nirchio, 2004; Bakhoum, Sayed-Ahmed & Ragheb, 2009) and appears to be due to high crosslinking ability that Tilapia show as part of their reproductive strategy. This ability was observed in the present study as it was found that the Tilapia of the Zimapan reservoir share characteristics from two species of Tilapia originally introduced in to the reservoir (*O. niloticus* and *O. aureus*). This cross gave rise to a hybrid *O. niloticus* X *O. aureus* with special features as shown in Table 1. The hybridization capacity of Tilapia has been utilized in aquaculture in order to obtain fast growing and disease-resistant organisms, however inbreeding in natural conditions has been known to cause downsizing and internal organ malformation, so it might be necessary to take action to renew the gene pool, such as implementing periodic restocking of the reservoir (López-Hernández et al., 2007), in order to keep a sustainable fishery and conservation of this resource.

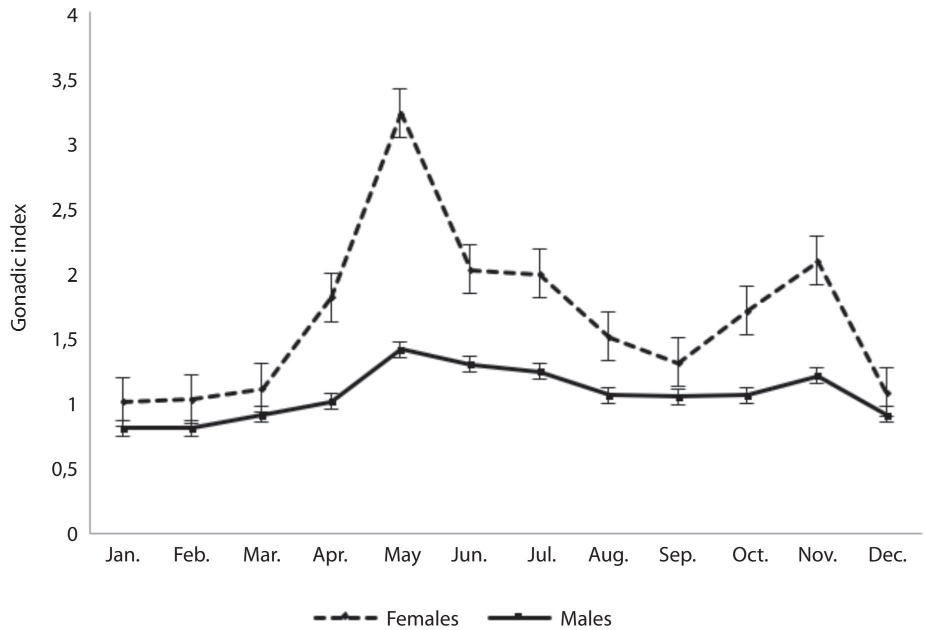

Fig. 7. Gonadosomatic index in Tilapia females (*Oreochromis aureus x Oreochromis niloticus*) by month.

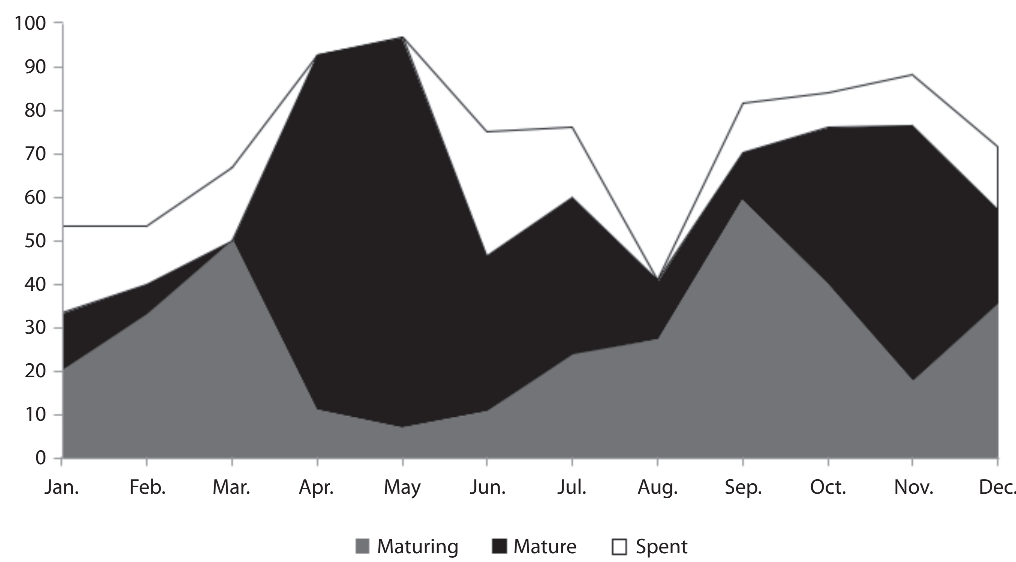

Fig. 8. Seasonal variation of maturity stages for *Oreochromis aureus x Oreochromis niloticus* ovaries.

Castillo (1989) and Arredondo, Beltrán & Torres (1994) considered that sexual maturity in Tilapias is reached between 10-18cm and a weight of 70-100g. Similarly, other authors like Cosson (2000), Huet (1978), and more recently Bocek (2003), found mature organisms of *O. niloticus* with a body height of 10 to 15cm. and weighing 40 to 100g, including other species like *O. aureus* who showed a minimum size of reproduction at 16 cm (Morales 1991). In the present work in Zimapan Dam, a length at reproductive maturity in females was observed at 20.8cm and 22cm in males. These results are in good agreement with Basurto (1995), who reported in the Chila Lagoon, Veracruz, Mexico, a minimum size at maturity of 23,5cm in females and 24,0cm in males of the

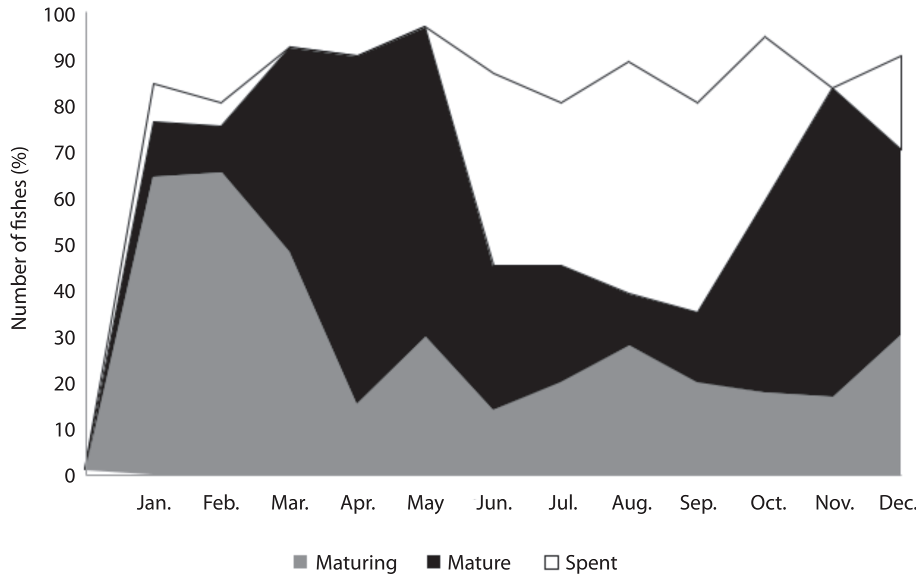

Fig. 9. Seasonal variation of maturity stages for *Oreochromis aureus x Oreochromis niloticus* testis.

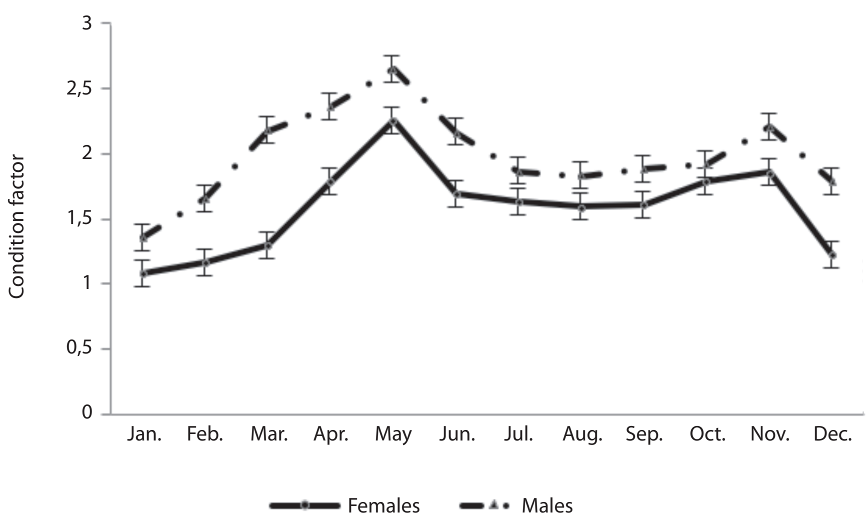

Fig. 10. Seasonal variation of condition factor (k) in females and males of *Oreochromis aureus x Oreochromis niloticus.*

Oreochromis niloticus, although the author mentioned that the commercial catch, due to the selectivity of fishing gear, did not represent fish under 20cm long . More recently in South Arabia, Khallaf, Galal & Authman (2003) reported that there is much variation in this parameter for *Orechromis niloticus* , influenced by human impacts and contamination of the sites where these fish live, together with the effect of the selectivity of fishing gear. Our results might be biased due to the selectivity of fishing gear concentrated in capturing the 21 to 25cm S_L range of fish. It would be desirable to make collections of smaller sizes to verify these results. According to our results, it appear that the minimum catch size for local commercial fishery established for Tilapia in Zimapan Dam (23,0cm S_L; Hernández-Montaño & Meléndez-Galicia, 2010), allows good conservation of the species, letting it to reach its reproductive size. By this procedure, mature organisms can reproduce and younger specimens are preserved.

The sex ratio for *O. niloticus* X *O. aureus* in Zimapan reservoir indicate that the male and females are approximately equal in numbers and the deviation from the 1:1 ratio (male: female) was not significant. Nikolsky (1963) cited that the sex ratio varies considerably from species to species, but in the majority of cases it is close to one, and may vary from year to year in the same population. Other studies have also reported on the 1:1 sex ratio in Tilapia (Ramos-Cruz, 1995; Shallof & Salama, 2008; Afamdi & Peter, 2008), as in this study. It is important to highlight the fact that some catches (between January and March) have shown a mean male number greater than females, although no significance difference were observed, except in March (Table 1).

Morales (1974) estimated fecundity from 1 000 to 1 800 eggs for female sizes between 31 and 33cm long in the Miguel Aleman reservoir, in Oaxaca, Mexico. Fryer & Iles (1972) obtained a fecundity of 3 706 eggs from a gigantic with total length of 57cm of *T. nilotica*. Jiménez-Badillo (1999) reported for *O. aureus* at Adolfo Lopez Mateos Dam in Michoacán, a range of 625 to 1 983 eggs for females from 13,9 to 28,0 cm, with an average of 1 304 eggs. Moreover Peña-Mendoza, Gómez-Márquez, Salgado-Ugarte & Ramirez-Noguera (2005) showed that Tilapias collected at Emiliano Zapata reservoir, Morelos, Mexico, presented a production of eggs from 243 to 847in organisms from 15 to 25cm long. The number of eggs produced in Zimapan reservoir gave an average of 3 000 eggs for a range of 17,9 to 25,9cm S_L, in good agreement with our results. Apparently, the "Zimapan" Tilapia, once they have reached reproductive maturity, have a size range in which the follicles or egg production is optimal (Fig. 3), but in young Tilapia and older fishes, the number of eggs produced is lower. This fertility, coupled with the parental care shown by these organisms (Chapman, 2000), increase the chances of survival.

The gonad index showed two peaks, one in May and another in November. This is indicative of the reproductive capacity of this species, which has been reported as a species that can perform several partial spawning over a period of annual. These reproductive characteristics have been reported in different reservoirs in Mexico and other sites of the world. Gómez-Márquez, Peña-Mendoza, Salgado-Ugarte & Guzman-Arroyo (2003), reported on Lake Morelos Coatetelco, two spawning periods for *Oreochromis* sp (June and December), Jiménez-Badillo (2006) found for blue *Tilapia* sp partial spawning, and has reported spawning peaks from May to August and October to November in Infiernillo reservoir. Shallof & Salama (2008) reported that females of *O. niloticus* had several spawning peaks, observed in March, April, June and September in the Egyptian lake Abu-zabal. Morales (1991) mentions that the frequency of spawning in Tilapia can vary considerably depending on environmental factors and Tilapia in Mexico might spawn up to 10 times per year. The same was reported by Afamdi & Peter (2008) for a lake of Nigeria. For Zimapán reservoir, the gonadic index indicated the existence of two reproductive periods occurring in May and November, in good agreement with a previous observation reported by Hernández-Montaño & Orbe-Mendoza (2002) and suggesting particular environmental conditions that only allow two reproductive seasons, compared to other reservoirs. This study revealed that fish closed season established from April to June (Hernández-Montaño & Orbe-Mendoza, 1999; Hernández-Montaño y Orbe-Mendoza, 2002; Hernández-Montaño &Melendez-Galicia, 2010; Arellano-Torres et al., 2013; SAGARPA, 2013), may have better results in preserve the local fisheries, considering that Tilapia has a second spawning peak in November as was observed in this study (Fig. 7). However, a more extent monitoring program needs to be performed by National authorities in order to justify this possibility, considering the amount of organisms from the whole population that is sexually mature, abundance and distribution in the reservoir and caught parameters on a year and monthly bases. This information will give the best season of capture according to national regulations for fish closed seasons (DOF, 2004). By establishing two closed seasons in Zimapan management program as our results suggest (April and November for example), better conservation of this resource could be reach, especially if we consider that the main productive activity in the region is the commercial fishery with a value greater than 2,3 million dollars or 30 million pesos per year (Hernández-Montaño & Meléndez-Galicia, 2010). Now days, April´s closed season allows a recovered in tilapia population and provides a greater volume of capture few months later (Hernández-Montaño & Meléndez-Galicia, 2010). The same pattern could be developed if a second closed season is established exactly when caught volumes are reduced, as has been observed in March and November for tilapia in Zimapan (Hernández-Montaño & Meléndez-Galicia, 2010). It is important to highlight that from a genomic point of view, Mexican regulation (DOF, 2000) does not considered hybrids of tilapia, only pure lineage, leaving it without suitable regulation. Therefore, we can conclude that these fishes are still eligible for commercial exploitation and its conservation, under the actual fishery management regulations can be improve by extending the fish closed season to a second period in November, by local authorities and fishermen, that could induce a higher volumes of captures (and income) few months later, just before the fish closed season of April.

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