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Reproduction, age and growth of the carp *Ctenopharyngodon idella* (Valenciennes, 1844); of southeast Mexico

Reproducción, edad y crecimiento de la carpa *Ctenopharyngodon idella* (Valenciennes, 1844); del sureste de México

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ABSTRACT

The purpose of the present study was to determine some aspects of the fishing biology, age and grown of *Ctenopharyngodon idella* during the 2018 annual cycle. One hundred specimens were collected from the Usumacinta River, Mexico. The gonosomatic (GSI), hepatosomatic (HSI) indexes, and condition factor (K) were determined. The age was estimated based on age rings counts in vertebrae and applying the von Bertalanffy growth model. Gonadal maturity stages were classified according to Nikolsky. The most frequent sizes were 60 and 70 cm TL. Males are smaller than females (Mann-Whitney, W = 2121.0 and 1094.5, $p < 0.001$). The length-weight relationship between females and males were statistically different (ANCOVA, $F1.106 = 268.54$, $p < 0.001$), and the general male-female proportion did not show differences ($X^2 11 = 16.88$, $p = 0.111$). The species presents two reproductive peaks (April and August). The relative fecundity is 78 (±28.63) oocytes/g. The studied population was constituted by ages between 1 and 9 years, being the age 4, 5 and 6 the most frequent. It is concluded that young specimens, probably due to high fishing pressure, compose the population structure of this species.
Keywords: Usumacinta River, fishery, cyprinid.

RESUMEN

El propósito del presente estudio fue determinar algunos aspectos de la biología pesquera, edad y crecimiento de *Ctenopharyngodon idella* durante el ciclo anual de 2018. Se recolectaron cien especímenes provenientes del río Usumacinta, México. Se determinaron los índices gonadosomático (IGS) y hepatosomático (IHS), así como el factor de condición (K) y se estimó la edad por medio la lectura de bandas de crecimiento en vértebras, aplicando el modelo de crecimiento de von Bertalanffy. Se clasificaron los estadios de madurez gonádica según Nikolsky. Las tallas más frecuentes fueron de 60 y 70 cm LT. Los machos son más pequeños que las hembras (Mann-Whitney, W = 2121.0 y 1094.5, $p < 0.001$). La relación longitud-peso entre hembra y machos fueron estadísticamente diferentes (ANCOVA, $F1,106 = 268.54$, $p < 0.001$), y la proporción general de sexos no mostró diferencias ($X^2 11 = 16.88$, $p = 0.111$). La especie presenta dos picos reproductivos en abril y agosto. La fecundidad relativa es de 78 (±28.63) ovocitos/g. La población estudiada estuvo constituida por edades entre 1 y 9 años, siendo la edad 4, 5 y 6 las más

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frecuentes. Se concluye que la estructura de población de esta especie, está conformada por especímenes jóvenes, debido probablemente a la presión por pesca.
Palabras clave: río Usumacinta, pesquería, ciprínido.

INTRODUCTION

The grass carp (*Ctenopharyngodon idella*) is one of the largest species of the Cyprinidae family. It is the only member of this genus and there are no known subspecies. Since the grass carp *C. idella* was introduced to Mexico at the end of the 19th century from China, it was widely distributed in northern and central Mexico, and it was later introduced in the rivers of southern Mexico. This species has outstanding qualities due to its high biological potential (high reproduction rates and adaptation to a variety of habitats and climates), resistance to handling and diseases. *Ctenopharyngodon idella* along with *Cyprinus carpio* and *Carassius auratus* are among the 25 exotic freshwater fish species for the central region of Mexico and together represent 12 % of dominant exotic species, being introduced to the country for aquaculture and weed control purposes (Baruah *et al*., 2014; Contreras-MacBeath *et al*., 2014; Silva *et al.*, 2014; Ahmad *et al.,* 2018).

In Mexico, it is cultivated in Aguascalientes, Chiapas, Coahuila, Durango, Guanajuato, Hidalgo, Jalisco, México, Michoacán, Puebla, Querétaro, San Luis Potosí, Sinaloa and Zacatecas states (INAPESCA, 2021). For the southeast of Mexico, and specifically for Tabasco and Chiapas states, this species has fishing importance (Mendoza-Carranza *et al*., 2013; Mendoza-Carranza *et al*., 2018), reaching in Tabasco a fishery production of 795 tons in live weight (CONAPESCA, 2021). Despite its fishery importance, grass carp represents a threat to the ecosystems where it occurs as its herbivory habits decrease habitat complexity by reducing plant structure (Amador-Del-Ángel & Amador-del ángel, 2014[a]; 2014[b]; Castillo-Domínguez, 2015).

Recent studies in *C. idella* are focused on cadmium toxicity effects, evaluation of hematological response after exposure to endosulfan, effects of copper sulfate on gill histopathology, structural changes in gills and musculature by exposure to chlorpyrifos and mercury. The effect of dietary alginate on growth performance and non-specific immunity of juvenile carp (Dahmardeh *et al.*, 2012; Atabati *et al*., 2015; Bala, 2016; Kaur & Jindal 2016; Vajargah & Hedayati, 2017; Hu *et al.*, 2021). On the other hand, studies on genetic diversity and phylogenetic relationships have been carried out in China, using SSR markers (Yu, 2014); as well as the variability of populations in China estimated using EST-SNP markers (Muhammad *et al*., 2022) and the analysis on the chemical composition and fatty acid profile of fillets (Hoseini, 2013). Likewise, evaluation of hematological and plasma indices in grass carp with reference to age, sex and hormone treatment (Ejraei *et al.,* 2015). Other studies evaluate the weight-length ratio of the species fed with balanced food and comparative studies of the retina of the eye with other fish species (Bhosale & Bhilave, 2014; She *et al*., 2014) and pathologies caused by cestodes (Ahmad *et al*., 2018). As seen in Mexico, basic and applied research on this species is

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very limited. The objective of this research is to determine some aspects of the reproductive biology, age and growth of the grass carp *Ctenopharyngodon idella* in the basin of the Usumacinta River, Tenosique, Tabasco, that will serve as base information for the implementation of ecological-fisheries strategies for a sustainable use and control of this introduced species.

MATERIAL AND METHODS

Study area and fish sampling

For this research, 100 specimens of *C. idella* were employed. These were collected during an annual cycle from January-December 2018 from commercial fisheries in the Usumacinta river basin, Tenosique, Tabasco. The catches of the specimens included the areas described by the fishermen as Crisóforo Chiñas (17°26'57.53 "N and 91°28'44.83 "W) and the locality of Chaculji (17°29'54.92 "N and 91°28'0.23 "W). The nets used for their capture were of the net tows (chinchorro) type with a mesh size of 4 cm, 80 m long and 3 m high.

Biometrics of the specimens

The total length (TL) and total width (TW) of each organism were obtained monthly, with a 100 cm ichthyomete with a precision of ±1.0 mm. Total weight (TW), gutted weight (GW), gonad weight (Wg) and liver weight (LW), were recorded with an OBI® 5000 g digital scale. All these with an accuracy of ±0.1 g, and a Torrey® 20 kg scale, with an accuracy of ±2 g. Sex determination in specimens was corroborated by direct observation of gonads during dissection (Rodríguez-Gutiérrez, 1992). Sex and maturity stages were determined based on the partial spawner maturity scales proposed by Nikolsky (1963), which comprises six stages: immature (I), inactive (II), maturing (III), mature (IV), spawning (V) and spent (VI).

Data analysis

Size frequency distribution was calculated, grouping organisms by 1 cm size class (Gulland and Rosenberg, 1992). An analysis of variance was used to test for statistical differences in overall means in TL after checking for normality and homogeneity of variances. The gonadosomatic index (GSI) was determined by the equation GSI= Wg / Wt x 100, where GSI= Gonadosomatic index, Wg= Gonad weight (g), Wt= Specimen weight (g) (Rodriguez-Gutierrez, 1992). The hepatosomatic index (HSI) was determined with the equation HSI= Wh / Wt x 100, where HSI = hepatosomatic index, LW = liver weight (g) and Wt = specimen weight (g) (Rodríguez-Gutiérrez, 1992). The physiological state or condition factor (K) of each specimen was obtained under the following equation: $K = W / L^b \times 100$.

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The length-weight relationship of *C. idella* was determined separately for both sexes by applying the equation $TW = a\ TL^b$ where TW= weight, TL= length, a= proportionality constant, b= the slope (growth coefficient).

Absolute fecundity was calculated as the relationship of maturing and mature oocytes in the ovary to the total fish weight. The estimate was developed by taking three subsamples of 0.3 g (±0.001) in three sections of the gonad (anterior, middle and posterior) and the equation Fa=n*G/g where G=total gonad weight, g = subsample weight, and n = average number of oocytes. Relative fecundity was estimated with the formula Fr=total oocytes/fish weight in g.

The average value of weight and length of males and females was compared using the Mann-Whitney (W) test for nonparametric data (Zar, 1999). A multiple correlation analysis and ANOVA was applied to the TL-TW regressions between sexes to identify possible differences between them (Sparre & Vanema, 1998). To determine possible differences in the monthly sex relationship, the Chi-square test (X^2) was used (Underwood, 1996).

To establish the age of each specimen, the first thoracic vertebra was removed from each specimen, rinsed with water, dried and placed in polyethylene bags labeled with the collection data. Subsequently, they were roasted under the burning technique, for a better visibility of the growth rings. Clove oil was used for clarification. Growth rings were counted from photographs using a stereo microscope with a MOTICAM® 2.0 digital camera. For age determination, three readers were assigned to identify annual growth rings from digitized photographs, the first reader detected and counted each opaque zone as a growth ring, and the assigned age was replicated and verified by a second independent reader. The third independent reader established any discrepancies in age estimates between readers 1 and 2. The age frequencies of the specimens were recorded according to the readings established by the readers for each vertebra. The von Bertalanffy growth model $Lt = L\infty\ (1\text{-}e\text{-}k(t\text{-}t0))$ was applied to determine the age-length relationship, where: Lt = average total length at age t; $L\infty$ = asymptotic total length; t0 = hypothetical length at age zero; k is the growth coefficient; and b is the slope of length. Growth parameters were considered for combined sexes using the Ford-Walford's linear method.

Environmental condition

Data on river level, rainfall and water temperature were obtained from CONAGUA (National Water Commission) weather station number 30019, located in Boca Del Cerro town, near the study area.

Ethical Statement

No special permits were required for sample collection because the fish used were from commercial fisheries. Commercial fishing permits cover these catches. At the time of dissection, these organisms were already dead and were handled under permission of the fishermen.

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RESULTS

Immature specimens presented a TL 27.50 to 37.5 cm (56.18 ± 16.15 cm). Males presented a TL 61.53 to 77.54 cm (68.5 ± 3.78 cm) with the 60 cm class being the most frequent. In females the TL was 40.00 to 81.5 cm (72.1 ± 7.29), with the 70 cm class being the most frequent. Males were significantly smaller in length and weight (medians (M) = 68.5 cm TL 3439.0 g TW, than females with M =72.0 cm TL 3986.0 g TW (Mann-Whitney, W = 2121.0 and 1094.5, $p < 0.001$). The relationship for females was $TW= 0.0457(TL)^{2.6617}$ and for males $TW= 0.1182(TL)^{2.4290}$. For both sexes the model obtained was $TW= 0.0526(TL)^{2.6244}$, and the percentage of variability of the data explained by the model (R^2) was 88 % for females, 72 % for males and 85 % for both sexes. The observed value of *b* for the TL-TW equation for both sexes is less than three, indicating that the species presents a negative isometric growth type (t_2 =1.00, $p<0.005$) (Figure 1). The length-weight relationship of female and males were significantly different (ANCOVA, $F_{1.106}$ = 268.54, $p < 0.001$).

Males accounted for 53 % of the organisms analyzed, while females accounted for 47 %, resulting in a male: female relationship of 1.1:1. The proportion of males was higher in February (88 %) and April (80 %), while females presented maximum values in May (89 %) and August (80 %). The relationship between males and females was statistically different in February (X^2_{11}= 4.5, $p = 0.034$) and May (X^2_{11}= 5.4, $p = 0.020$). The overall sex relationship showed no difference (X^2_{11}= 16.88, $p = 0.111$). In October and November, it was not possible to capture specimens, due to the increase in river level.

The maximum GSI values in females occurred during April (15.52) and August (9.12). In January, June and December the GSI was less than 2.8. In males, the maximum GSI values were observed in July (2.17) and September (2.41), in the months of January, June and December the GSI was below 0.68 (Figure 2).

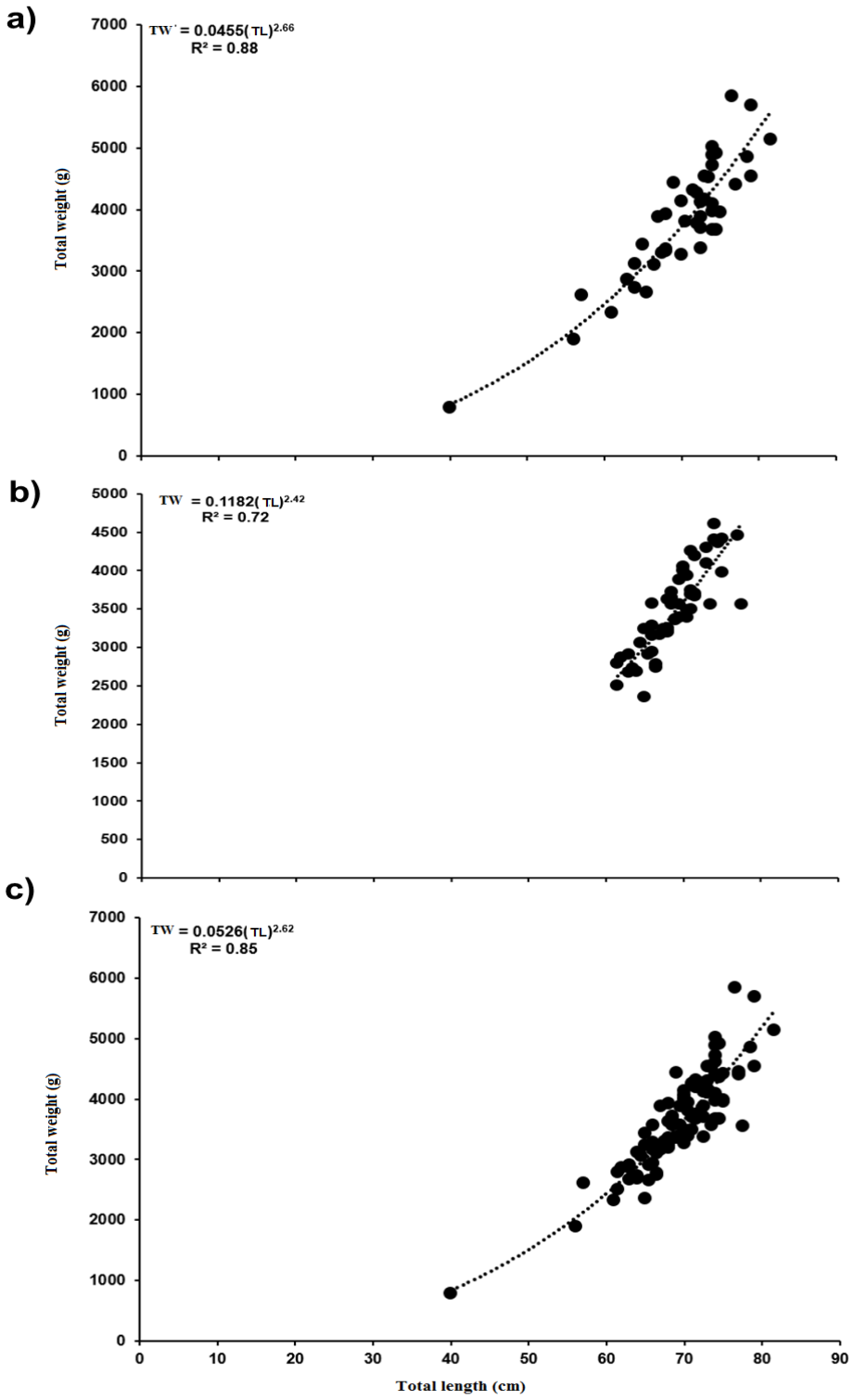

Figure 1. Length-weight relationship in females (a), males (b) and both sexes (c) of *C. idella* (N = 100) from the Usumacinta River, Tabasco, Mexico. TW = Total weight, TL = Total length, R^2 = Coefficient of determination

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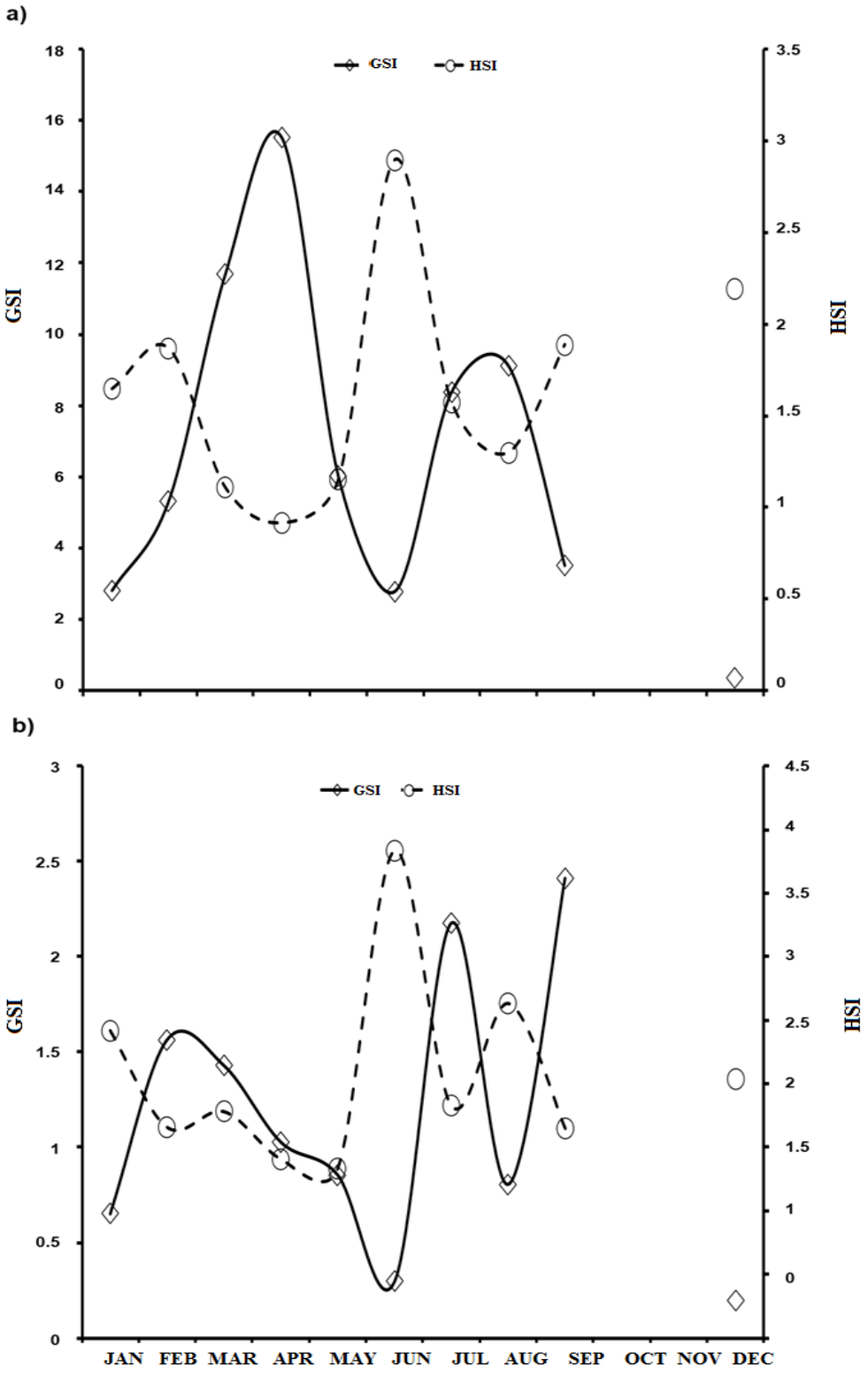

Figura 2. Monthly variation of the gonadosomatic index (GSI) and hepatosomatic index (HSI) in females (a) and males (b) of *C. idella* from the Usumacinta River, Tabasco, Mexico (N = 100**)**

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The hepatosomatic index (HSI) in females showed its maximum values in June (2.91) and December (2.3) while the minimum was recorded in April (1.17). For males, the maximum values were recorded in June (3.18) and August (2.33) and the minimum in May (1.17). K values for both sexes had little variability throughout the year, showing a slight increase for females in March, June and September, with maxima in March for females (1.69) and December for males (1.59). The minimum values for females were 1.29 during April and 1.14 for males in August. The macroscopic description of the maturity stage of *C. idella* gonads is described in Table 1 and Figure 3.

Table 1. Macroscopic description of gonadal maturity stages of *C. idella* from the Usumacinta River, Tabasco, Mexico (based on Nikolsky, 1963)

Stage	Description
Immature (I)	Ovary small and elongated, few translucent, near the dorsal wall and below the swim bladder. Testes are pinkish filiform and poorly vascularized, with a location similar to that of the ovaries. They occupy approximately ½ half of the coelomic cavity.
Inactive (II)	Ovaries are enlarged pink, vascularized with a cylindrical appearance in the posterior part. The oocytes are not distinguishable macroscopically. They occupy approximately 1/2 to 1/3 of the coelomic cavity. Elongated testes with a slight increase in size, red coloration and increased vascularization.
Maturing (III)	Ovaries increased in size of uniform olive green color, dilated vascularization along the gonad, oocytes observed with the naked eye in the form of granules. They occupy 2/3 of the coelomic cavity. Testes markedly increased in size and soft consistency, the appearance of lobules on the periphery of the testis is appreciated. They are white in the posterior part and pinkish in the anterior part.
Mature (IV)	Ovaries of yellow color, with increased vascularization, occasionally with lobule formation along the gonad due to the increase in size of the oocytes. They occupy between 2/3 of the coelomic cavity. White colored testis, increased in size with amorphous aspects by lobules arranged lengthwise, indicating an increase in content.
Spawning (V)	Ovaries of partially flaccid with spherical oocytes, some oocytes transparent and hydrated prior to being expelled. They completely occupy the coelomic cavity and show slight vascularization. The testis is increased in size with amorphous lobules more marked than in the previous stage. The seminal fluid is expelled with simple pressure.
Worn (VI)	Very flaccid ovaries with distended membranes and hemorrhage in the anterior part. They occupy 1/3 of the coelomic cavity. Remaining oocytes with granular appearance are observed. Testis occupying the coelomic cavity similar to the ovaries. Reduced in size with flaccid appearance in the anterior part, slightly thickened middle part and posterior part of greater thinness, due to the expulsion of sperm fluid.

Absolute fecundity in *C. idella* (n = 26) was in females weighing 2.318 – 5.845 g (X = 4.091g ± SD 771.34 g). This fecundity was 36.736 – 607.780 oocytes (X = 320.887 ± SD = 133.549.38). Relative fecundity was 14 - 125 oocytes/g (X = 78 oocytes/g ± SD=28.63 oocytes/g).

The studied population of *Ctenopharyngodon idella* from the Usumacinta River consisted of eight age groups between 1, 3 and 9 years (Figure 4). For both sexes, ages 4, 5 and 6 were the most frequent (28 %, 25 % and 22 %, respectively). It is important to mention that no specimens belonging to age group 2 were obtained. The average error rate among the three readers was 8.26 % with a coefficient of variation of 8.45 %.

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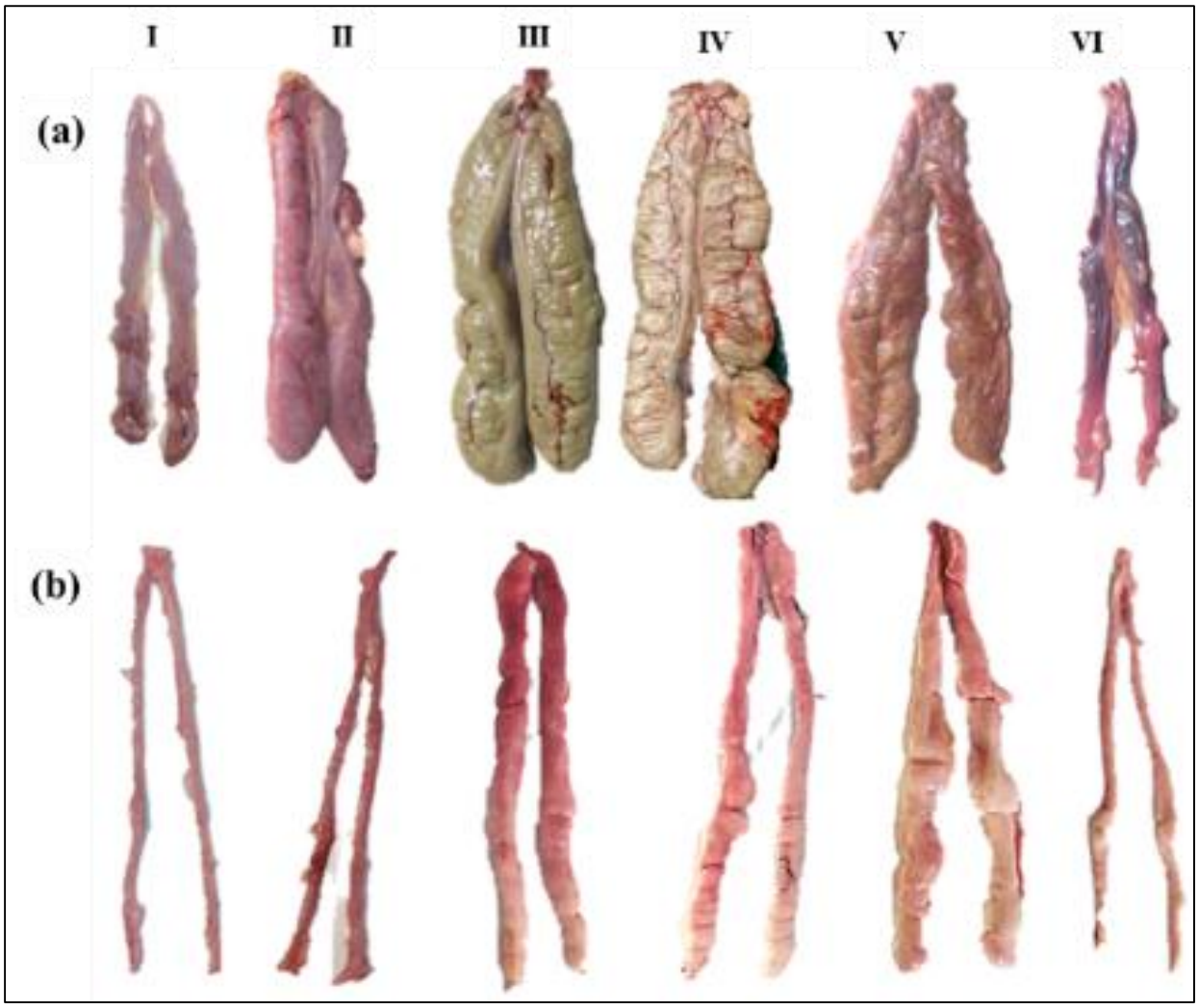

Figure 3. Images of gonad maturity stages in females (a) and males (b) of *C. idella* captured in the Usumacinta River, Tenosique, Tabasco. I = Immature, II = Inactive, III = Maturing, IV = Mature, V = Spawning and VI = Worn

The von Bertalanffy growth equation for both sexes was $TL\infty = 72.03(1-e^{0.46(t-0.553)})$, for females was $TL\infty = 74.26(1-e^{0.55(t-0.5568)})$ and for males was $TL\infty = 51.02\ (1-e^{0.289(t-0.280)})$. Water temperature ranged from 23°C in December to 30°C in May. Precipitation ranged from 1.9 mm in March to 22 mm in November. The Usumacinta River level reached its lowest value in April, at 11 m a.s.l., obtaining the greatest depth (19.11 m) in October. Rainfall was high throughout the second half of the year, beginning in June with 10.7 mm and ending in December with 14 mm.

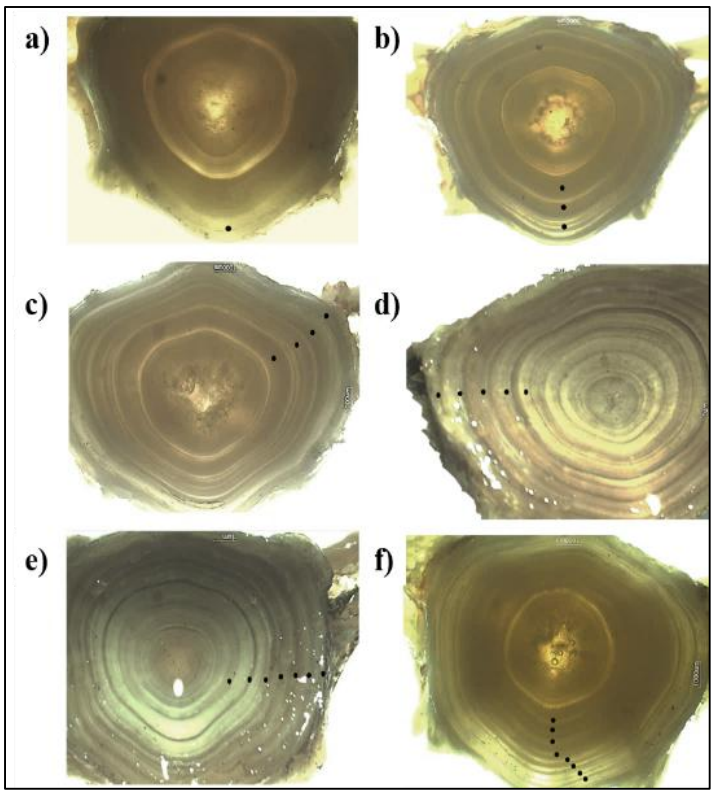

Figure 4. Images of vertebrae of *C. idella* showing the age of organisms captured in the Usumacinta River, Tabasco, Mexico. Black dots represent age: one-year (a), three years (b), four years (c), five years (d), seven years (e) and eight years (f)

DISCUSSION

This research is the first to be conducted on the reproductive biology of grass carp in the hydrological accounts of Mexico, so it was not possible to compare our data with previous studies, since most studies are focused on its fisheries importance (INAPESCA, 2021; Mendoza-Carranza *et al*., 2018). Despite this lack of studies related to biological-fishery data, it is observed that the TL (cm) and weight (g) recorded were similar to growth in captivity (Sherrat, 2020). The frequency in TL and weight recorded was lower than that reported for this same species in Western Europe, but were similar to those recorded in the fishery resources of the Usumacinta River in Mexico (Milardi *et al*., 2015; Mendoza-Carranza *et al*., 2018). The size structure of *C. idella* depends on the environment in which they live, mainly in terms of food availability, population density and ecological factors. Therefore, the recording of these lengths in this study may be conditioned by a migratory behavior of the species, as is the case of other species, such as *Labeo rohita*, *Barbus graellsii*, *Chondrostoma miegii* (Miñano *et al*., 2000; Mir *et al*., 2013).

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Analysis of length-weight relationship for females and males indicates that these are statistically different, similar data to those recorded by Hailu, (2013) and Khalid & Naeem, (2017) in a tropical reservoir (Amerti: Ethiopia) and Southeastern Pakistan, respectively.
The male: female ratio in the present study was similar, the records by Hailu, (2013) for common carp (*Cyprinus carpio*). However, in the present study there was difference in this ratio in the month of February that was favorable to males and on May was favorable to females. It is relating it to the reproductive indices for these months; it can be observed that males mature first than females, with the purpose of preparing to spawn in the month of April, where the highest gonadosomatic index was recorded.
The GSI in *C. idella* indicates an activity starting in February with a maximum peak in April and August in females, behavior that is related to the reproductive peaks of males during the annual cycle studied. These records are similar to those reported in the Nile River at a temperature of 20 °C. As well as with specimens from a reservoir in Sri Lanka, where reproductive peaks occur in the month of October. However, in the present study, no specimens were captured in this month due to the increase in the level of the Usumacinta River (Abd-Elhakim *et al*., 2019; Nathanael & Edirisinghe, 2021; Sheha *et al*., 2021). In carp, final maturation and spawning could occur within a 24-h period following environmental cues (water temperature, dissolved oxygen) and stimulating factors (specific climatic conditions, the presence of herbaceous vegetation, opposite sex and rainfall or flooding) for spawning to be present, and this likely accounts for increased GSI during the reproductive period. If these signals do not appear within a certain period, at the gonadal level, atresia or reabsorption of a portion of the vitellogenic oocytes occurs (Nathanael & Edirisinghe, 2021). On the other hand, *C. idella* has high reserves of essential fatty acids such as Ω-3 and Ω-6, which contributes to the reproductive success of the species (Bibi & Muhammad, 2021).
The hepatosomatic index for *C. idella* in the present study shows similarity to that recorded for the species in the Nile River of Egypt (Abd-Elhakim *et al*., 2019).
In the present study the length distributions were relatively wide, ranging from 55 to 110 cm, which, are within the age of first sexual maturity in males of 53 cm in length reported by Sheha *et al*., (2021) and those reported by Abd-Elhakim *et al*., (2019) of 62 cm for females and 53 cm for males.
The fecundity of the species in this study resulted similar to that reported by Maiztegui, (2015); Khalid & Naeem, (2017) and Jones *et al*., (2017) for *C. idella* and *C. carpio*, respectively.
One of the important environmental parameters for the growth and reproduction of grass carp is water temperature. In this research resembles those reported by other authors on the biological aspects of the species, mentioning tolerances from 0 to 33 °C. It, and that temperatures above 38 °C, that are lethal for adults, and the water temperature in which they are stimulated to sexual maturity is between 20 to 30 °C, but generally between 20

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and 22 °C. These parameters are similar to those recorded for the species *Cyprinus carpius* (Laverde & Hernando, 2012, Tessema *et al*., 2020).

The most frequent ages of *C. idella* in the present study for both sexes were 4, 5 and 6 years, being these ages different from those reported in Eastern Europe (from 7 to 17 years) (Milardi *et al*., 2015), these differences may indicate the impact of the fishery to which the species is subjected in the Usumacinta River. In addition, they are within the age recorded in this same species in two reservoirs: Patterson and Bowman-Haley in North Dakota in the U.S. State, which ranged between 2 and 24 years through the study with fin rays and between 2 and 27 years with dorsal fin spines (Weber *et al*., 2011). Other species studied in the same family present this variability; such is the case of the species *Labeo rohita* where the highest age recorded was 8 years with a TL of 86.22 to 90. 45 cm; also in the species *Barbus graellsii* and *Chondrostoma miegii* recording specimens of 10 and 8 years of age, and of *Gobio lozanoi* with ages of 7 and 8 years; *Luciobarbus callensis* of 4 and 7 years. To some extent, these variations are the product of the plasticity of the species to adapt to different environments (Miñano *et al*., 2000; Amat-Trigo *et al*., 2013; Mir *et al*., 2013; Mimeche *et al.,* 2013).

In this study, the adaptability of *Ctenopharyngodon idella* to the environmental and ecological conditions of the Usumacinta River in southeastern Mexico is confirmed. However, being an exotic species, it is among the most important, least controlled and irreversible impacts that occur in ecosystems and that affect their biodiversity in a very important way; as well as, they can strongly modify the hydrology, the biogeochemical cycle and the biotic composition of invaded ecosystems (Strayer, 2010; Traveset, 2015). On the other hand, the large volumes with which species are caught have positively impacted the economy of fishermen, since, although they do not have a high commercial value, they represent a good income for their families. Likewise, these species have modified the dietary patterns of the surrounding communities, a source of affordable animal protein for these communities due to the economic value at which they are marketed (Mendoza-Carranza *et al*., 2018).

CONCLUSION

The biological-fishing aspects demonstrate the adaptive capacity of the species in southeastern Mexico, specifically in the Usumacinta River basin. It is a species with two maximum peaks of sexual maturity, in July and September for males, and in April and August for females. The most frequently captured ages of *C. idella* for both sexes were 4, 5 and 6 years old. This indicates that, according to the data obtained in this research, fishing exploitation is mainly of young organisms. It is important to continue with these studies to provide biological, ecological and commercial information in different geographic and temporal areas with the objective of establishing a fishing management of this species that is being subjected to strong fishing pressure.

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Errata Erratum

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