Reproductive biology of *Menidia jordani* (Atheriniformes: Atherinopsidae) in Xochimilco Lake, Mexico

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The reproductive biology of *Menidia jordani* (Woolman, 1894), a native fish of Mexico and one of the most important commercial fish species in Central Mexico for centuries, was analyzed. A monthly sampling between April 1995 and March 1996 was carried out. Sex ratio was 1.5:1 (female:male), determined by simple observation. Females were larger than males, the largest sizes being 7.2 cm for females and 6.3 cm for males. Standard length at first maturity was 4.8 cm for females and 5.5 cm for males. Monthly variations in gonadosomatic index (GSI), hepatosomatic index (HIS) and ovarian development stages showed that the spawning season occurred mainly from January to May. Best correlation values were between fecundity and length (r = 0.7383; p = 0.0003), compared to those found between fecundity and weight (r = 0.6132; p = 0.002). Fecundity ranged from 143 to 952 eggs per female; mean fecundity was 324 eggs.
Key words: Mesa silverside, gonadosomatic index, gonadic maturity, sex ratio.

Biología reproductiva de *Menidia jordani* (Atheriniformes: Atherinopsidae) en el Lago de Xochimilco, México

Se analizó la biología reproductiva de *Menidia jordani* (Woolman, 1894), pez nativo de México, que por varios siglos ha sido una de las especies de peces comercialmente más importantes en el centro de México. Los muestreos se realizaron mensualmente de abril 1995 a marzo 1996. El sexo de los peces fue determinado macroscópicamente y la proporción de machos fue significativamente más baja que la de hembras, 1.5:1 (hembra:macho). Las hembras alcanzaron tallas más grandes (longitud patrón) que los machos, la mayor en hembras fue de 7.2 cm y 6.3 mm en machos. La primera madurez fue de 4.8 mm de longitud patrón en hembras y de 5.5 mm en machos. La variación mensual de los índices gonadosomático (IGS) y hepatosomático (IHS) y el desarrollo del ovario mostraron que el desove se realiza predominantemente de enero a mayo. El valor de correlación fecundidad-longitud fue más alto (r = 0.7383; p = 0.0003) que para fecundidad-peso (r = 0.6132; p = 0.002). La fecundidad varió de 143 a 952 huevos por hembra con una media de 324 huevos.
Palabras clave: Charal, índice gonadosomático, madurez gonadal, proporción de sexos.

Introduction

Geographic distribution of Atherinopsidae ranges from the tropics to temperate areas. Nelson (1994) found that most members of this family concentrate in marine shoreline areas; about 50 species are found in freshwater, among them is the genus *Chirostoma*, which belongs to the subfamily Menidiinae (Chernoff, 1986), with 18 extant and one extinct species (Barbour, 1973a).

The genus *Chirostoma* is divided into two groups: *Jordani* and *Arge*. *Jordani* group contains all of the relatively large species known in Mexico as "white fish", while the smaller species belong to the *Arge* group, known as "charales" or silverside. All members of the genus are endemic to central Mexico and live in freshwater, but they

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share many features with marine Atherinopsids because of their common ancestry (Barbour, 1973a; Miller *et al*., 2005). Reports on their systematics, biology, distribution and ecology have been carried out by Álvarez del Villar (1970) and Barbour (1973b). Recently Miller *et al*. (2005) placed all silversides of Mesa Central in the genus *Menidia* Bonaparte, a classification that is adopted in this study for *Menidia jordani*.

"Charales" are a group of species of economic, social, cultural and ecological importance in central region of Mexico, mainly in Pátzcuaro and Chapala lakes and commonly called "white fish" (*M. estor*, before *Chirostoma estor*), along with several other silversides such as *M. jordani* (previously *Ch. jordani* Woolman (1894)); (Álvarez del Villar, 1970; Miller *et al*., 2005).

The mesa silverside fish or "charal" *Menidia jordani*, inhabits clear, turbid or muddy and quiet waters of lakes, rivers, ponds, canals, and reservoirs up to 1 m depths (Miller *et al*., 2005). They feed on zooplankton, insects, small fishes and sometimes snails. Some species of *Chirostoma* and *Odontesthes* are economically relevant, either for sport fishing, artisanal fisheries or aquaculture.

While *Menidia jordani* is a very important fishery resource, it is currently in danger due to environmental changes in Xochimilco Lake, and because of its high value and demand in regional markets, providing an incentive for local fishers to capture small juveniles and adults in an indiscriminate way.

Various aspects of the biology of commercially important "charales" have been studied by De Buen (1945), Barbour (1973a; 1973b), Gallardo (1977), Navarrete (1981), Gómez and Ramírez de Arellano (1982), Burali (1989), Cházaro (1989), Rodríguez (1989), Peralta (1991), Hernández (1993), Islas *et al*. (1995[1]), Jiménez and Gracia (1995), Cárdenas and Barrera (1998), Soria-Barreto and Paulo-Maya (2005), Martínez-Palacios *et al.* (2006), Rojas-Carrillo (2006), and Ibáñez *et al.* (2008).

1. Islas, Y. J., F. Arana y R. Pérez. 1995. Estudio preliminar sobre la reproducción en cautiverio de *Chirostoma jordani* Woolman (Pisces: Atherinidae) de la zona lacustre de Xochimilco, D. F. Segundo Seminario Internacional de Investigación de Xochimilco. Asociación Internacional de Investigadores de Xochimilco A.C., pp: 342-345.

To understand the reproductive biology of *M. jordani*, the variation of gonadic maturity stage, sex ratio, weight-length relationship, first reproductive size and reproductive season were determined on a yearly basis.

Materials and methods

Xochimilco Lake (19° 17' 28" and 19° 15' 58" N; 99° 04' 05" and 99° 06' 54" W) is located at 2 274 m altitude in Mexico City (INEGI, 2000) (Fig. 1). It has a surface area of approximately 24 km^2, up to 10 m in depth and a mean of 2 m. Samples were performed monthly from April 1995 to March 1996.

Fish were captured with a 30 m length seine with a 0.01 m mesh size. All fish were measured for total length (TL) and standard length (SL) to the nearest 1 mm, weighed (total weight TW) to the nearest 0.1 g and dissected to determine sex. Gonadic maturity stage was categorized according to Nikolsky (1963).

Gonads and liver were removed and weighed to the nearest 0.01 g. Each month, sex ratio was determined for the entire sample. Mean length at first reproduction was established according to King (1995), based on the length at which 50% (Lm) of all individuals were sexually mature.

A covariance analysis was conducted to determine whether or not there were significant differences at $p<0.05$ for the length-weight relationship between both sexes. The standard length (SL)-total body weight (TW) relationship was calculated by a power regression between these variables for each sex using the formula:

$$TW = aSL^b \qquad \text{Eq. 1}$$

where TW is the body weight, SL the standard length, *b* the growth exponent or length-weigh factor, and *a* is a constant. The values of a and b were estimated by means of a linearized form of that equation by taking (base 10) logarithms on both sides and estimating the values of log (a) and log (b) by means of a linear regression, using ordinary least-squares regression. Student's *t*-test was used to the hypothesis of isometric growth (Ricker, 1975; Pauly, 1984).

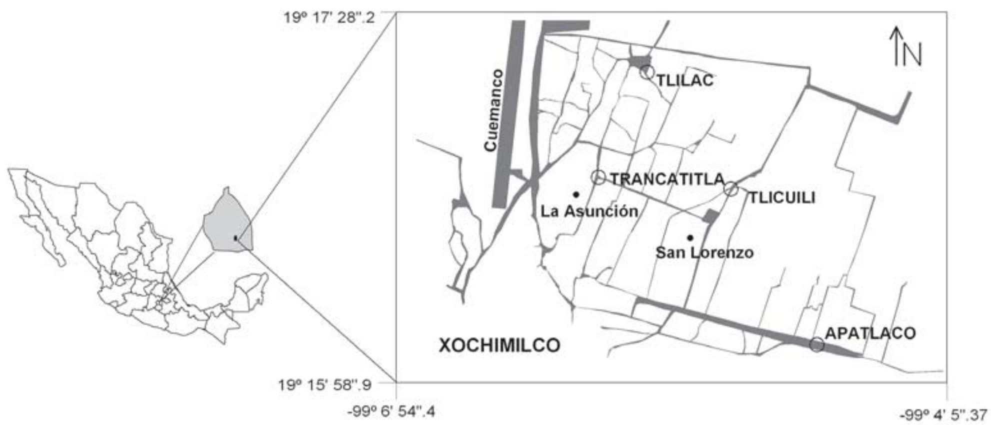

Fig. 1. Xochimilco Lake, Mexico, showing study site.

Gonadosomatic index (GSI) was calculated for each individual based on the relationship between gonad weight (GW) and total body weight (W), expressed as a percentage (Vlaming *et al.*, 1982). Hepatosomatic index (HSI) was calculated for females based on the relationship of liver weight (LW) and (W), expressed as a percentage. Each month, values of gonad stage frequency and mean values of GSI and HSI were plotted to graphically visualize the reproductive cycle and breeding season of the fish.

For an estimate of fecundity, ripe females (n = 294) were used, taking the total number of eggs contained in the gonads (Laevastu, 1971; Bagenal, 1978). The variation of fecundity with fish body length was estimated (Bagenal, 1978). Mean fecundity values were calculated according to Shoesmith (1990).

Environmental factors were considered in the analysis to determine if there is a relationship to the fishes' breeding cycle. Surface temperature was recorded at 10:00 h during each sampling event. Previous water temperature data from 1995 and 1996 were incorporated for the analysis. Maximum depth was recorded using a weighted line. Chlorophyll *a* was measured using a Thermo Scientific Spectronic 20 spectrophotometer (Wetzel and Likens, 1991).

Results

Total sample size of *M. jordani* was 2 986 individuals. Standard body length and weight ranged from 2.9 to 6.3 cm and 0.32 to 3.18 g for males, and from 4.0 to 7.2 cm and 0.73 to 5.37 g for females. Females were larger than males (*t*-value = 11.39; $p<0.05$) (Fig. 2).

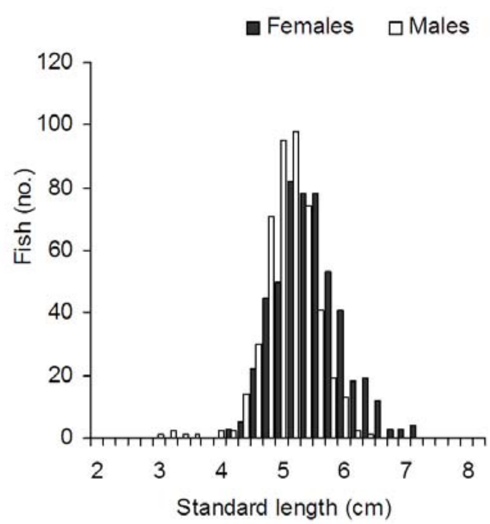

Fig. 2. Length frequency distribution by sex for *Menidia jordani* at Xochimilco Lake, Mexico.

From the total dissected individuals, 1 183 (40%) were males and 1 803 (60%) females. Sex ratio was 1.5:1 (female: male), and differs significantly from a 1:1 ratio ($\chi^2 = 129.10$; $p<0.05$). Except for June and January 1996 (Fig. 3), sex ratio showed monthly variation.

Due to a significant difference in male and female slopes of TW-SL regressions (ANCOVA; $F = 32.82$; $p<0.05$), the length-weight relationship was calculated for all individuals, and for

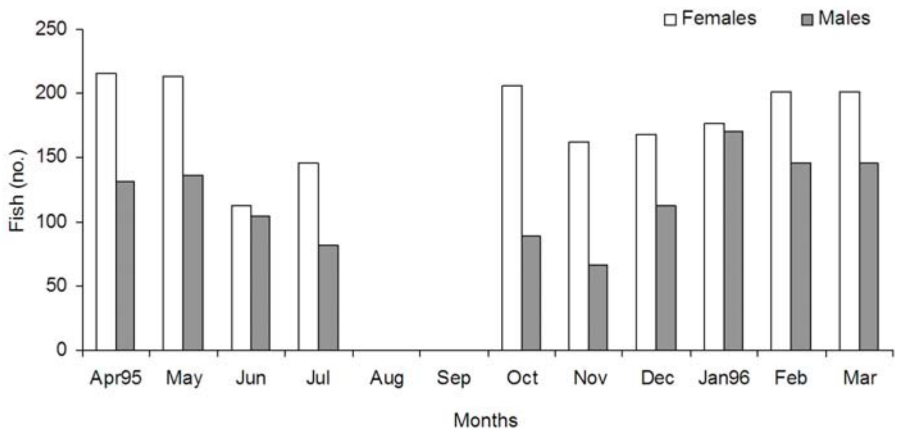

Fig. 3. Monthly sex ratio for *Menidia jordani*.

each sex separately. These equations are given as follows:

Females:	$W = 0.015\ SL^{2.946}$, $r^2 = 0.9078$
Males:	$W = 0.018\ SL^{2.826}$, $r^2 = 0.8808$
All fish:	$W = 0.015\ SL^{2.940}$, $r^2 = 0.9079$

Weight increases allometrically with size (Fig. 4) since the b value was significantly different than 3 (*t*-value = 2.010, $p<0.05$ for females, and *t*-value = 3.595, $p<0.05$ for males). Length being equal, females were heavier (*t*-value = 12.72; $p<0.05$) than males.

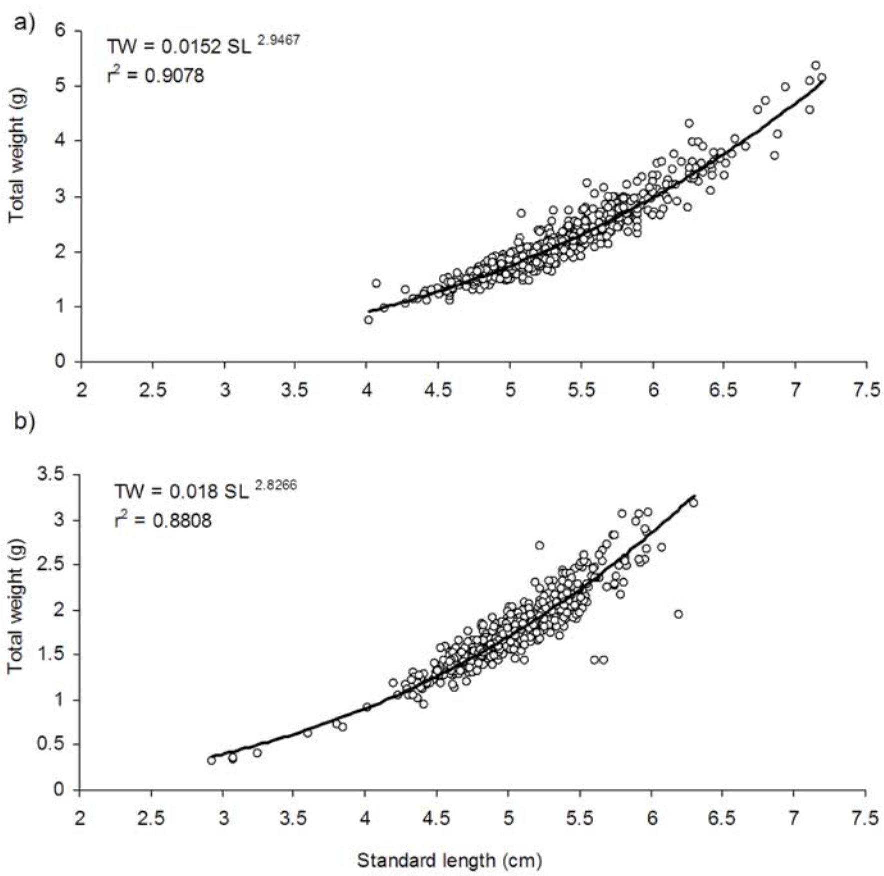

Fig. 4. Length-weight relationship for females (a) and males (b) of *Menidia jordani*.

Maturity stages

The proportion of gonadic development stages of females (Fig. 5) showed that 68% were at immature stage (II), 23.1% maturing (III), 5.4% mature (IV), 2.7% ripe (V) and 1% had spawned (VI). Therefore, 31.2% of the females were in the reproductive process. Male gonadic development (Fig. 6) showed that 57% were at immature stage (II), 22.9% maturing (III), 18.6% mature (IV), 1.1% ripe (V) and only 0.4% had spent (VI). Therefore, 42.6% of the males were in the reproductive process.

The highest proportion of mature (IV) and ripe (V) females was found from January to May (Fig. 5), suggesting a full spawning season. Fishes in spent stage (VI) were not observed from September to December. Mature and ripe males were found from January to July (Fig. 6); stage VI was not observed from July through March.

Size at first maturity

The relationship between body length and gonadic development was analyzed for all 2 986 specimens. Young males and females attain maturity at their first year of life. Through a logistic curve fitted values method, estimated mean standard lengths at sexual maturity (Lm) showed 4.8 and 5.5 mm for females and males, respectively.

Fecundity

Standard length in a sample of 294 females ranged from 4.4 mm to 6.9 mm, whereas total weight ranged from 1.3 g to 4.56 g. Individual fecundity

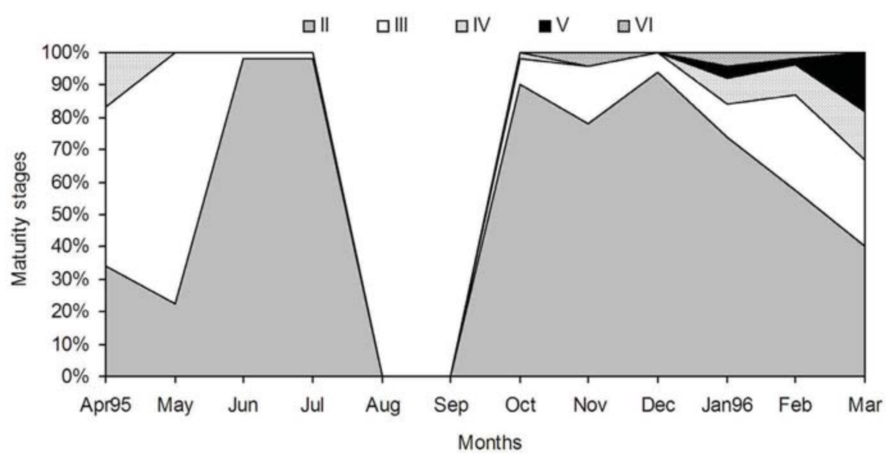

Fig. 5. Seasonal variation of maturity stage development for females of *Menidia jordani*.

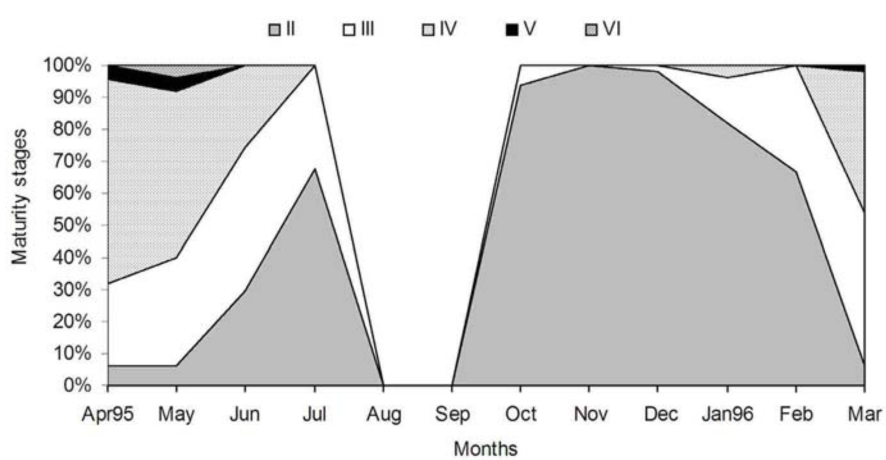

Fig. 6. Seasonal variation of maturity stage development for males of *Menidia jordani*.

varied from 143 and 952 eggs per female and increased with length. This length-weight relationship can be described as:

$F = 5.506\ SL^{2.3994}$ (in size)
$F = 122.6\ TW + 44.49$ (in total weight)

The fecundity - body weight relationship resulted in a lower correlation value ($r = 0.6132$, $p = 0.002$) than fecundity-body length ($r = 0.7383$, $p = 0.0003$). Mean fecundity was 324 eggs. The number of ripe oocytes increased with ovarian weight.

Gonadosomatic (GSI) and hepatosomatic (HSI) index

Monthly variation in GSI due to fish size is considered to be very high, due to a significant variation in fish length between months ($F = 9.12$, $p<0.05$), and the variance of GSI within each month is statistically different (Levene's test: 3.688; $p<0.05$). Therefore, GSI values for females varied significantly among months (Kruskal-Wallis; $H = 258.15$, $p<0.05$); this was also true for males (Kruskal-Wallis; $H = 319.18$, $p<0.05$). Maximum values of gonadosomatic index for females and males were obtained in March (Fig. 7), and also indicate a high reproductive effort.

The mean values of the hepatosomatic index (HIS) varied significantly between months (Kruskal-Wallis $H = 88.96$; $p<0.05$), and the variances of HIS within each month were not equal (Levene's test: 14.17; $p<0.05$). The minimum value of HIS for females was recorded in December 95 (2.73); and February 1996 (1.76) for males, right before the spawning season.

Environmental factors

Based on water temperature, maximum depth and chlorophyll *a* values for Xochimilco Lake were characterized with two seasons: a dry season (November to May) and a rainy season (June to October) (Fig. 8). Water level on the Lake increased following the "heavy rains" from August to October. Water temperature at the lake ranged from 14.5 °C to 24 °C, and was relatively high from April to June during this study. Low temperatures were recorded from December to February. Chlorophyll *a* data showed that phytoplankton biomass peaks occurred during November and from March to May (Fig. 8).

Discussion

Menidia jordani is a dimorphic species with differing sex-specific growth rates. Silverside or "charal" females live longer, reach larger sizes than males, and can feed on a large array of prey and avoid predation successfully, which decreases their mortality rate. This aspect was observed for *C. jordani* by Navarrete (1981), Gómez and

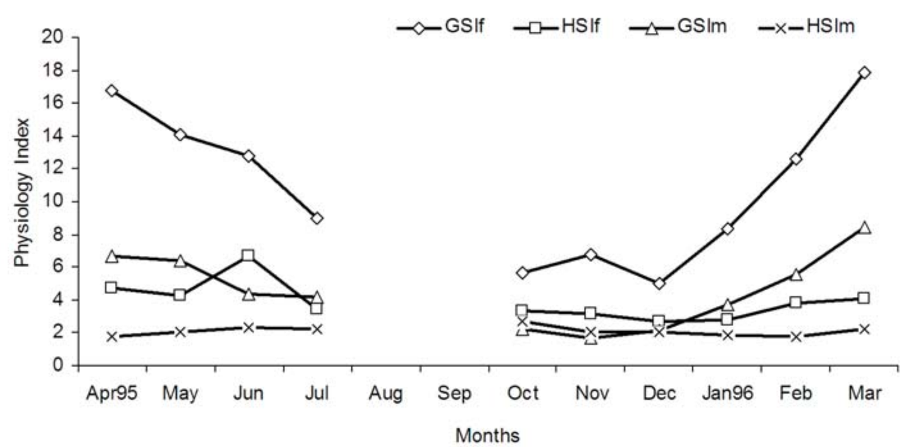

Fig. 7. Seasonal variation of the gonadosomatic (GSI) and hepatosomatic index (HSI) for females (f) and males (m) of *Menidia jordani*.

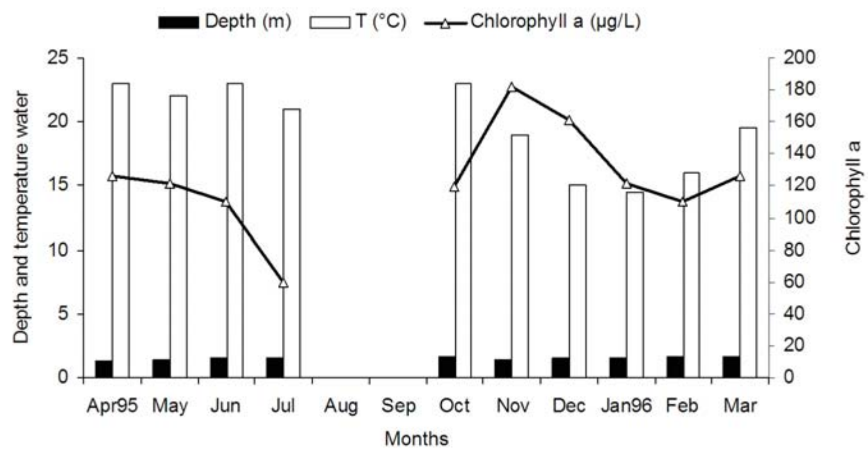

Fig. 8. Seasonal variation of chlorophyll *a* concentration (µg/L), depth (m) and water temperature (°C) at Xochimilco Lake, Mexico.

Ramírez de Arellano (1982), Hernández (1993), and for *C. attenuatum* by Rojas-Carrillo (2006).

Nikolsky (1963) mentioned that the larger sizes of females result from a differential growth rate with respect to males. Conover and Kynard (1981) pointed out that in natural *M. menidia* populations, more females are produced early in the breeding season and hence are generally older and larger than males. Also, Conover and Heins (1987) cited that in nature, most offspring produced earlier in the breeding season, while the temperature is relatively low, become female; later in the breeding season, when temperature is higher, offspring develop into males. Females are thereby afforded a longer growing season and tend to be larger than males. Therefore, in our study, females probably have higher survivorship rates due to their larger size, are longer-lived than males, and are more resistant to the rigors of reproductive effort. Also, faster growing individuals usually have a higher fecundity rates than slower growing ones of the same size (Conover, 1984).

Chazaro (1989) cited that the larger size of *C. jordani* is influenced by changes in the food supply and represents an adaptive response of the population to environmental changes.

Sex ratio for *M. jordani* in Xochimilco Lake indicates that males and females have different abundances, and in this case deviation from the expected 1:1 (male:female) was significant. This is supported by other studies on the same species in different aquatic systems (Gómez and Ramírez de Arellano, 1982; Hernández, 1993; Ibáñez *et al*., 2008). However, Gallardo (1977) and Rodríguez (1989) mentioned that the sex ratio for *C. chapalae* was of 2.5:1 to 5:1 male:female, and was considered a common feature. Rojas-Carrillo (2006) cited a sex ratio of 2-3 males per female for *C. attenuatum*. Nikolsky (1963) pointed out that the sex ratio varies considerably from one species to another, but in the majority of cases it is close to one, and may vary from one year to the next in the same population. Moreover, in this study the male:female sex ratio was 1:1.5 and variations in sex ratio reflect natural population dynamics.

With respect to a differential sex distribution, Van Aerle *et al.* (2004), Devlin and Nagahama (2002) and Guerrero-Estévez and Moreno-Mendoza (2009) pointed out that there is a large variety of mechanisms of sexual determination. These may be genetic, or depend on environmental conditions such as temperature, pH, and community factors, all of which can influence sexual proportion in a population. According to Devlin and Nagahama (2002), temperature fluctuations in the different habitats where fish dwell may alter biochemical pathways of sexual determination and act upon an individual to induce male or female development.

Conover and Kynard (1981) mentioned that the first teleostean species where sex determination was described as dependent on temperature is *M. menidia.* At that time, an adaptive function was postulated. On the other hand, Conover (1984) stated that in natural *M. menidia* populations, ocean temperature affects sexual proportion. In cold temperature conditions, females are produced, and this was associated with a longer time of ovary growth. Similarly, low temperatures can also induce sexual differentiation towards a higher percentage of females in the Atherinid *Odontesthes bonariensis* (15 to 19 °C), and at 29 °C, was observed that all the individuals of a population are males (Strüssmann *et al.,* 1996).

In addition, van Aerle *et al.* (2004) points out that there are a wide range of chemicals discharged into the environment that mimic hormones, especially estrogens, and sex steroids play an important role in the regulation of sexual differentiation. Moreover, he cited that field studies exposing caged fishes to effluents from sewage treatment works have shown that chemical exposure can reduce gonad growth, feminize duct development in males, and alter germ cell development and gender assignment. Therefore, the determination of sex and skew in *M. jordani,* probably is a phenomenon that is affected by environmental factors as has been also cited by Rojas-Carrillo (2006).

Another aspect that could also have some influence on fish survival is the size at first reproduction, because females are precocious compared to males, which have a shorter growth period prior to maturation and therefore lower growth rates. This means that the females take advantage of being precocious and have a longer reproductive life, while males delay maturation.

The size at maturation of *M. jordani* is not exceptional. Similar sizes at first maturation have been reported by Ibáñez *et al.* (2008) in the lake of Meztitlán, Hidalgo. Lower length values were reported by Navarrete (1981), Cházaro (1989), and Hernández (1993). However, the size at first maturation of this species is small compared with other species in different aquatic systems. Martínez-Palacios *et al*. (2006) found that *C. estor estor* achieve maturity within the first year, when their total length is between 12 and 15 cm. Rojas-Carrillo (2006) mentioned that *C. attenuatum* of lake Páztcuaro, Michoacán has its first maturity size at 8.1 cm SL.

This difference arises because the sexual maturity is a function of the size and may be influenced by abundance and seasonal availability of food, temperature, age, day length and other environmental factors at different localities (Nikolsky, 1963; Uria *et al.,* 1998).

Menidia jordani reaches sexual maturity at a small size within its first year of life (48 and 55 mm SL) and is therefore able to begin to reproduce in January. The monthly trend shown by GSI variation suggests that, in the population analyzed in this study, gonadic growth begins in October/November and continues in April/May when most of the individuals in the population are spawning. In addition, seasonal trends of mean values of GSI can be used as a good indication of the population spawning season. With the gonadosomatic index, hepatosomatic index and gonadal development stages together, it is evident that the reproduction peak occurs from January to May, during the dry season. Ibáñez *et al.* (2008) have shown similar results for the same species in Meztitlán, Hidalgo. Rojas-Carrillo (2006) mentioned for *C. attenuatum* that a similar type of reproductive activity occurs throughout the year, but the maximum intensity occurs between April and May. Rosas (1976[2]) pointed out that in *C. humboldtianum* the reproductive period occurs between March and June.

Fecundity range was from 143 to 952 eggs, lower than that observed by other authors for *C. jordani*. Navarrete (1981) obtained fecundity from 745 to 1 870 eggs; Cházaro (1989) cited 658 eggs, and Hernández (1993) reported from 564 to 1 102 eggs.

Wootton (1990) mentioned that the number of eggs that a female spawns over a defined time period depends on the number of eggs per spawning and the number of spawnings. Moreover, the number of eggs produced per spawning is a function of body size, as was observed in this study. Females of the same size do differ in their fecundities and the same female can have different fecundities within the same breeding season (Bagenal, 1978). Therefore, there is a tendency for the value to be higher in marine species than

2. Rosas-Moreno, M. 1976. Datos biológicos de la ictiofauna del lago de Pátzcuaro con especial énfasis en la alimentación de sus especies. *Memorias del Simposio de pesquerías en aguas continentales*. Tuxtla Gutiérrez, Chis. Noviembre 1976. Tomo II: 299- 366.

in freshwater species, and lies most commonly between 3.25 and 3.75.

With respect to the relationship between length and weight, Ricker (1979) mentioned that when fish have a *b* coefficient value significantly different from three, the growth is allometric. This is the case of the present study, body grows slower in weight than length, and an exponent less greater than 3 would indicate that the fish becomes less heavy as it increases in size. Similar results have been found for Navarrete (1981), Gómez and Ramírez de Arellano (1982) and Hernández (1993). In addition, the relationship between length and weight provides an index frequently used by fisheries biologists to quantify the state of well-being of a fish (Wootton, 1990).

The reproductive cycle of "charal" in the lake is primarily determined by temperature, seasonal fluctuations of day length, rainy season (when the water is not totally transparent and the productivity is high), and water level that increases between July and September, when nutrients for development are available. Those parameters affect the timing of the spawning season. In most species of fish, breeding activity increases during periods of intense sunshine and/or rainfall. In this study, a major breeding peak of charal was associated with warm temperature water. The period with high values of GSI was also the time of the increase in phytoplankton biomass (chlorophyll *a*) at Xochimilco Lake. Phytoplankton biomass in this aquatic system is shown to increase following high nutrients levels due to water mixing and rainfall associated changes in the lake hydrology.

This increase in phytoplankton biomass may be one of the environmental cues for an approaching favorable season for better growth and survival of the offspring, while the other environmental factors may have indirect effects. A similar conclusion can also be drawn for other species such as *Sarotherodon (Oreochromis) macrochir* of Lake McIlwaine (Marshall, 1979), for *O. niloticus* in Lake Awassa studied by Admassu (1996) and for *O. niloticus* in Emiliano Zapata Dam, Morelos State (Peña-Mendoza *et al*., 2005). Nevertheless, more detailed research is required to investigate the effect of phytoplankton on the time of breeding of *M. jordani* in Xochimilco Lake.

A coincidental relationship between the GSI and seasonal changes in rainfall and air temperature indicates that spawning occurs mainly in the warm and rainy season. The results presented here suggest a positive relationship between these abiotic variables and reproduction.

The "charal" *M. jordani* is an important economic resource in the central region of México and many families depend almost exclusively on its fishery, making it an important food resource. Although most of the freshwater fisheries in México are being depleted, largely owing to interactions with introduced non-native species (Miller *et al*., 2005). Nowadays, aquatic ecosystems are possibly the most affected by human activity. They receive a great quantity of pollutants from large cities, industrial parks, and from livestock and agricultural activity. In addition, aquatic species are subject to indiscriminate exploitation as a source of food, and aquatic ecosystems are in a definite process of deterioration. Thus, their preservation requires immediate attention.

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