



Assessment of the reproductive biology of largemouth silverside *Chirostoma arge* (Atherinopsidae) in Lake Chapala, Mexico

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Abstract

Chirostoma arge (Jordan and Snyder, 1899) is a fish endemic to the central plateau of Mexico important for fishing in natural reservoirs such as Lake Chapala. Unfortunately, little is known about this species of the Atherinopsidae family, which is listed as Data Deficient by the IUCN Red List. This study's objective was to determine the sex ratio, the stage of gonadal maturity in each sex, the spawning season and to estimate the relative condition factor, the minimum standard length and the standard length at first maturity. It analyzed a 3195 fish specimens caught by fishers from six landing sites during an annual cycle. The sex ratio was significantly skewed toward males; however, females recorded a higher mean weight and length than males. Spawning in both sexes began in March and lasted until July. The monthly gonadosomatic index values showed significant increases in females and males from January to May. The monthly variation in condition factor showed a significant increase from November to May. The standard length at first maturity or L_{50} in females (80.4 mm SL) was slightly greater than in males (77.8 mm SL). The mean fecundity was 1778 eggs (± 582 SD). A positive correlation was found between fecundity and ovary weight. This study provides biological and fisheries data on the reproductive activity of one of the most abundant species of silverside, *C. arge*, in Mexico's largest lake, Lake Chapala.

Keywords: charal; condition factor; Lake Chapala; maturity; sex ratio; silverside; spawning

1 | INTRODUCTION

Mexico's freshwater fish fauna is notable not only for its species richness but also for its high number of endemic species, which is largely because Mexico lies between two biogeographical regions, the Nearctic and the Neotropical (Espinosa *et al.* 2011). According to Miller *et al.* (2009), Mexico's freshwater fish fauna comprises more than 540

species, grouped into 155 genera and 50 families, including quasi-endemic families such as Goodeidae and Lacanotidae and those with a high number of endemic species such as Cyprinidae, Poeciliidae, Cyprinodontidae, Cichlidae and Atherinopsidae (Vega-Salazar 2003). Special attention should be given to fish of the Atherinopsidae family and, in particular, those of the *Chirostoma* genus,

which, despite being marine in origin, successfully invaded freshwater environments (Navarrete and Cházaro 1992). *Chirostoma* is the most abundant and diverse genus in this family, comprising a group of fish of great ichthyological, ecological, economic and sociocultural importance (Barriga-Sosa 2003), endemic to the Central Mesa of Mexico (Barbour 1973; Miller *et al.* 2005) that have played an important role in the diet of the region's inhabitants since prehispanic times (Aguilar and Navarrete 1996). It comprises 18 species and six subspecies (Barbour 1973; Echelle and Echelle 1984; Rojas-Carrillo and Fernández-Méndez 2006), some of which are included in the list of endangered species (DOF 2010). The genus *Chirostoma* is divided into two groups: the Jordani group, consisting of large fish known as “white fish,” and the Arge group, consisting of small fish called silversides (Aguilar and Navarrete 1996).

The silversides (*Chirostoma* spp.) are strictly freshwater fish endemic to the Mesa Central of Mexico, yet they bear similarities to other Atherinopsidae due to their marine origin (Barbour 1973). They are slender, laterally compressed fish of small size (6–12 cm in length), characterized by a silvery band on their flanks, an elongated and flattened head, a blunt snout, a small mouth with teeth and thick, protractile lips and two dorsal fins (Miller *et al.* 2005). In adulthood, they are considered primary zooplankton-feeding carnivores that form shoals of dozens of individuals. In terms of reproduction, they are oviparous with external fertilization, exhibit no parental care and spawn during the spring months (Arredondo-Vargas *et al.* 2013). They inhabit streams, lakes and spring-fed ponds, often in turbid, flowing waters with substrates composed of firm sand, clay, mud and rock. Silversides not only represent an ichthyological treasure requiring preservation, but for centuries have also served as an important protein source and high-value economic resource for rural artisanal fisheries (Barriga-Sosa 2003). In addition, species of the arge group are currently threatened by overfishing driven by high commercial demand, leading to significant population declines in *Chirostoma* spp. (Lyons *et al.* 1998; Martínez-Palacios *et al.* 2002). The mean annual catch of silversides in Lake Chapala over the last decade (2014–2024) was 1662.63 t (± 1571.23 t), with peak catches recorded in 2016 (9831 t) and 2017 (7205 t) that have not been observed since (CONAPESCA 2025).

The largemouth silverside *Chirostoma arge* (Jordan and Snyder 1899) is distributed across the Pacific slope of Mexico, in tributaries of the Lerma River basin, the upper Verde River and particularly Lake Chapala. Despite its ecological relevance, empirical data regarding its population biology and life history remain limited. Morelos-López and Guzmán-Arroyo (1995) documented the synonymy and morphometric traits of *C. arge*, reporting a standard length of 65 mm. Lyons *et al.* (1998) noted its presence and status in the Lerma River system and Lake

Chapala, documenting declines in its geographic range and overall abundance alongside the local extinction of *C. charari* and *C. compressus* (Soto-Galera *et al.* 1998). Reflecting these ongoing threats, the IUCN Red List classifies *C. arge* as a species with insufficient data or Data Deficient, emphasizing its status as a species endemic to the Lerma River basin (Froese and Pauly 2025).

Habitat degradation is another factor that contributes to this decline, driven primarily by anthropogenic activities such as waste disposal from human settlements, deforestation, agriculture, livestock farming and industry (Saunders *et al.* 2002). Similarly, pressure exerted by non-native species introduced into Mexican freshwater systems (Contreras-Balderas *et al.* 2008) displaces native populations through direct competition, predation, disease transmission, habitat modification or trophic alterations within communities (Torres-Orozco and Pérez-Hernández 2011). Fluctuations in lake water levels also affect silverside populations by altering physicochemical parameters such as temperature and turbidity, which in turn influence overall abundance and species dominance patterns (Guzmán-Arroyo and Ortiz-Martínez 1995; Lévêque 1997; Moncayo *et al.* 2011a, 2011b). Therefore, the objective of this study was to evaluate key aspects of the reproductive biology of *C. arge* in Lake Chapala, Mexico, by determining its sex ratio, identifying stages of gonadal maturity and the spawning season and estimating length at first sexual maturity.

2 | METHODOLOGY

2.1 Study area

Lake Chapala is located in west-central Mexico (20°21'18"N 103°26'30"W) within the Lerma-Chapala-Santiago basin (Figure 1). Covering an area of 8660 km², it is a large, shallow, turbid lake (Lind and Dávalos-Lind 2002) of vital socio-economic importance to local populations (Guzmán-Arroyo *et al.* 2003). As with most tropical freshwater bodies, its hydrological dynamics are driven by distinct rainy and dry seasons, which dictate water inflow and regulate physicochemical parameters (Filonov *et al.* 2001). The area features a summer rainfall pattern with a total annual precipitation of 875 mm (INE 2003). Terrestrial vegetation surrounding the reservoir is characterized as subtropical scrub (Estrada *et al.* 1983), transitioning to oak and oak-pine forests at elevations above 2000 m above sea level. Aquatic vegetation includes Montezuma cypress (ahuehuete) and willow (sauce) along the riparian zone, tule and reed as emergent vegetation, water lily (lirio) as floating vegetation and tripilla as submerged vegetation (Guzmán 1989).

2.2 Sample sites, fish collection and laboratory analysis

Biological sampling was carried out monthly from October 2016 to September 2017 with the cooperation of commercial fishers at six landing sites along the shores of Lake

Chapala: San Pedro de Itzcán, Chapala, Ajijic, San Luis Soyatlán, Mismaloya and Petatán (Figure 1). All specimens were obtained directly from commercial landings at these six sites; therefore, this study did not involve the use or handling of live specimens.

Commercial catches were harvested using gillnets and specialized cylindrical silverside traps (charaleras) (Figure 2). The charalera trap consists of a mesh cylinder measuring 1.5 m in length, supported by metal rings 0.5 m in diameter. Two rings positioned 15–20 cm apart at the top hold eight inverted funnel entrances constructed from cut 2-L plastic soft-drink bottles, allowing silversides to enter while preventing escape. Both ends of the cylinder are sealed with fine mesh. To keep the charalera trap afloat, several buoys (empty capped plastic containers) are secured to the top of the net. In addition, bundles of recycled netting (at least two) are attached to the sides of

the upper inner ring to attract silversides and encourage them to enter through the funnel openings (Figure 2a). Fishers targeting silversides deploy 20 to 30 charalera traps spaced 2 to 3 m apart along each main line at each fishing site. These lines are checked daily during morning hours throughout the fishing season. The gillnets used are rectangular, measuring 100 m in length and 1 to 2 m in width, with a main mesh size of 5 to 7 cm and an end mesh size of 0.5 to 1 cm. Collected fish samples were preserved on ice in coolers at approximately 4°C and transferred to the Laboratory of Ecology at the Centro Universitario de Ciencias Biológicas y Agropecuarias, Universidad de Guadalajara, where they were stored frozen at –20°C until processing. To evaluate reproductive activity, a monthly subsample of 50 specimens was selected from each capture site.

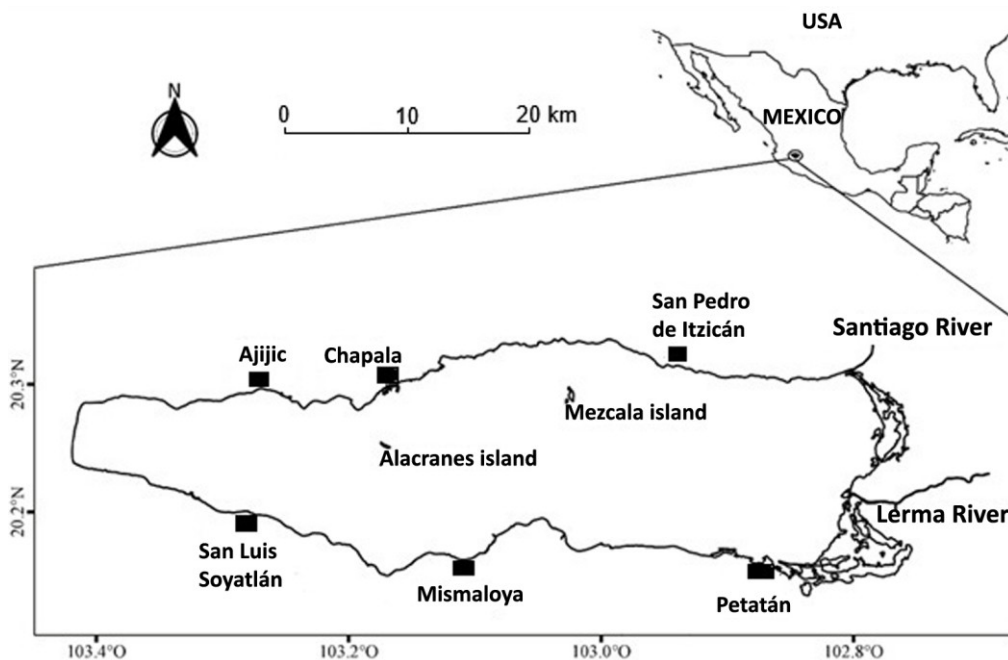


FIGURE 1 Location of fish landing sites along the shores of Lake Chapala, Mexico.

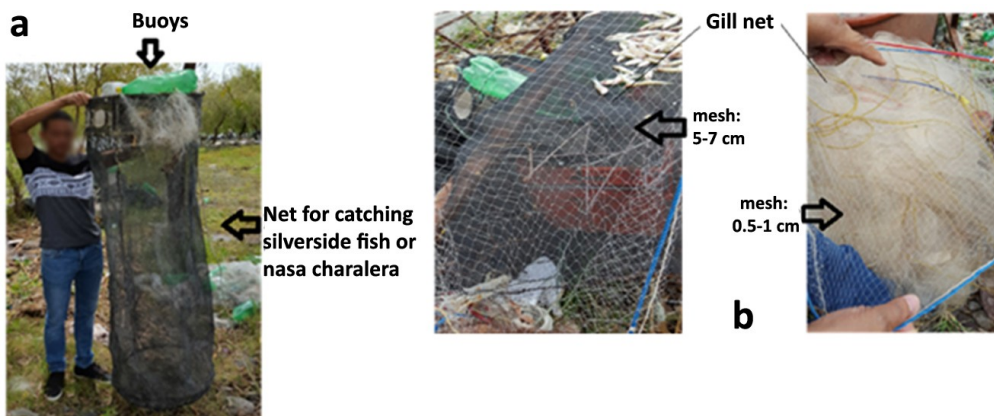


FIGURE 2 Charalera net (a) and gillnet (b) used by silverside fishers on Lake Chapala, Mexico.

In the laboratory, total length (TL) and standard length (SL) of each *C. arge* specimen were measured to the nearest 0.1 mm using a digital caliper, and total

weight (TW) was recorded to the nearest 0.0001 g using an analytical balance. The gonads and liver were removed from each specimen and weighed on the same balance.

Monthly gonadal maturity stages were assigned for each specimen by macroscopic observation following the criteria of Nikolsky (1963).

2.3 Data analysis

Total length (TL) and total weight (TW) data grouped by sex and sampling month were subjected to the Kolmogorov–Smirnov test for normality and Bartlett's test for homogeneity of variance. When assumptions of normality or homoscedasticity were violated, non-parametric equivalents were used. To evaluate differences in TL and TW between sexes across monthly samples, a Mann-Whitney *U* test was applied.

To establish the breeding season, a seasonal analysis of the proportions of the different stages of sexual maturation was carried out. The gonadosomatic index (GSI) and hepatosomatic index (HSI) were calculated relative to TW for each specimen following the procedures proposed by Introzzi and Introzzi (1986): $GSI = (\text{gonad weight}) / (\text{total weight}) \times 100$ and $HSI = (\text{liver weight}) / (\text{total weight}) \times 100$. The relative condition factor (K_n) was estimated monthly using Clark's formula (1928) to evaluate variations in somatic condition: $K_n = (\text{total weight}) / (\text{standard length})^b \times 100$, where b is a growth constant.

Monthly variations in estimated indicators, such as the GSI, HSI and K_n across sampling sites, were evaluated using one-way analysis of variance and Tukey's multiple comparison test when assumptions of normality (Kolmogorov–Smirnov test) and homoscedasticity (Bartlett's test) were met. When data failed to meet these assumptions, the Kruskal–Wallis test was used. All statistical tests were performed using the SigmaStat version 3.5 (2007) software package.

The mean size at sexual maturity was estimated by constructing a relative cumulative frequency curve for all mature females and males in stages III, IV and V (Barba 1990). The critical size, (L_{50}), at which 50% of the specimens have already reached a defined stage of sexual maturity (Arancibia *et al.* 1994), was calculated in accordance with Echeverría (1987): $P_{SL} = 1 / 1 + e^{(aSL+b)}$, where: P_{SL} is the percentage of mature specimens at a given standard length, SL is standard length, a and b are regression constants.

To estimate minimum size at maturity (L_{25}), a simple linear regression was applied between gonad weight and the SL of females and males in stages III, IV and V (Barba 1990). Based on cumulative frequency, the minimum size at first maturity was determined as the size at which 25% of the population (L_{25}) is in the reproductive phase.

Potential fecundity (F) was estimated from the total number of mature oocytes in each ovary following the equation developed by Hunter *et al.* (1992): $F = (\text{mean number of eggs counted in three subsamples}) \times (\text{gonad weight}) / (\text{subsample weight})$, where each subsample weighed 0.01 g. Fecundity estimates were performed on

female specimens captured during April and May at maturity stage IV, when ovaries exhibit mature characteristics in size and texture.

3 | RESULTS

A total of 3195 *C. arge* specimens were collected across six sampling sites in Lake Chapala, Mexico between October 2016 and September 2017. Overall, females were larger (SL: $U = 579.2$, $p < 0.001$) and heavier (TW: $U = 647.7$, $p < 0.001$) than males according to the Mann-Whitney test.

3.1 Sex ratio

The sex ratio was significantly skewed toward males across all months and sampling sites according to the Chi-square test ($\chi^2 = 84.3$, $p < 0.001$), although in March, April, August and September the ratio was 1:1 (Table 1). Regarding specific sampling sites, males were more abundant in Ajijic and Chapala, while females were more abundant in San Luis Soyatlán; at the remaining three sites, the ratio was 1:1.

3.2 Stages of maturity

The resting and developing stages (stages I and II) were predominantly observed from June to September. The maturing stage (stage III) extended from November to April in females and from October to February in males. Ripe gonads (stage IV) were present from October through April in both sexes. Spawning specimens (stage V) were recorded from March to July, with peak spawning activity occurring in May for both females and males, alongside a secondary spawning period in September for males (Figure 3).

3.3 Gonadosomatic index (GSI)

One-way analysis of variance revealed significant differences in the monthly variation of GSI for females ($F = 10.77$, $df = 11$, $p < 0.05$) and males ($F = 52.28$, $df = 11$, $p < 0.05$) (Figure 4). Tukey's post hoc test indicated that GSI values from January to May were significantly higher than those in the remaining months ($p < 0.001$).

3.4 Hepatosomatic index (HSI)

One-way analysis of variance revealed significant differences in the monthly variation of HSI for females ($F = 31.08$, $df = 11$, $p < 0.001$) and males ($F = 13.12$, $df = 11$, $p < 0.001$) (Figure 5). Tukey's post hoc test indicated that HSI values from May to September differed significantly from the remaining months ($p < 0.001$).

3.5 Condition factor (K_n)

One-way analysis of variance revealed significant differences in monthly K_n values for females ($F = 9.448$, $df = 11$, $p < 0.001$). Similarly, the Kruskal–Wallis test showed sig-

nificant monthly variation in K_n for males ($H = 28.617$, $df = 11$, $p = 0.003$). For both sexes, K_n values increased significantly from November through May before declining markedly from June to September (Figure 6).

3.6 Mean and minimum size at sexual maturity (SL_{50} and SL_{25})

The standard length at first maturity (SL_{50}) for females and males is shown in Figure 7, with a mean SL_{50} of 80.4 mm in females and 77.8 mm in males. The SL_{25} or minimum size at maturity in females was 71.8 mm SL and 70.7 mm SL in males.

3.7 Potential fecundity

A total of 67 mature females in stage IV were analysed across the six sampling sites in Table 2. Mean potential fecundity was estimated at 1778 (± 582 SD) oocytes per female, ranging from a minimum of 962 to a maximum of 3636 oocytes. Across sampling sites, potential fecundity did not vary significantly according to the Kruskal–Wallis test ($p > 0.05$). However, females from San Luis Soyatlán, Mismaloya and Ajijic had greater standard length and total weight than those from Chapala, San Pedro Itzicán and Petatán. These differences may reflect greater gonad volume, larger oocyte size and/or a higher number of oocytes in females from the former three sites.

TABLE 1 Monthly sex ratio of *Chirostoma arge* collected from Lake Chapala, Mexico, from October 2016 to September 2017 across six sampling sites. F = female; M = male.

Month / Site	Total	Female	Male	Ratio (F:M)	χ^2	p-value
Month						
Oct	19	3	16	1 : 5.3	8.894	<0.001
Nov	176	70	106	1 : 1.5	7.363	<0.001
Dec	300	107	193	1 : 1.8	24.653	<0.001
Jan	300	71	229	1 : 3.2	83.213	<0.001
Feb	300	127	173	1 : 1.3	7.053	<0.001
Mar	300	147	153	1 : 1.0	0.12	0.72
Apr	300	161	139	1 : 0.8	0.161	0.20
May	300	133	167	1 : 1.2	3.853	0.04
Jun	300	116	184	1 : 1.5	15.413	<0.001
July	300	103	197	1 : 1.9	29.453	<0.001
Aug	300	149	151	1 : 1.0	0.013	0.90
Sep	300	151	149	1 : 0.9	0.013	0.90
Site						
Ajijic	550	139	411	1 : 2.9	134.516	<0.001
Chapala	552	180	372	1 : 2.0	66.782	<0.001
Mismaloya	500	258	242	1 : 0.9	0.512	0.47
Petatán	535	255	280	1 : 1.0	1.168	0.27
San Luis Soyatlán	530	302	228	1 : 0.7	10.332	<0.001
San Pedro de Itzicán	528	204	324	1 : 1.5	27.272	0.06
Total	3195	1338	1857	1 : 1.3	84.307	<0.001

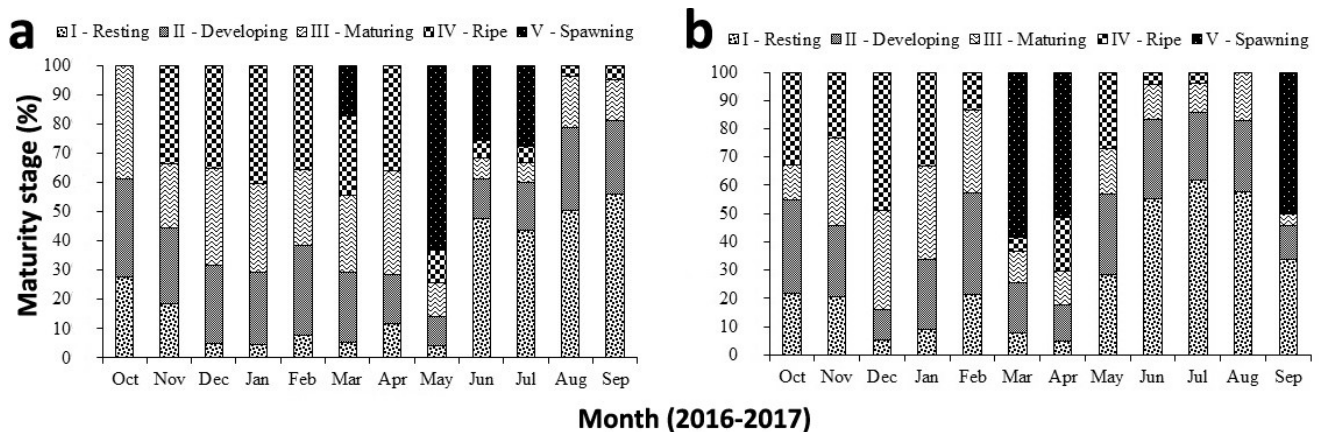


FIGURE 3 Stages of maturity in female (a) and male (b) gonads of *Chirostoma arge* in Lake Chapala, Mexico.

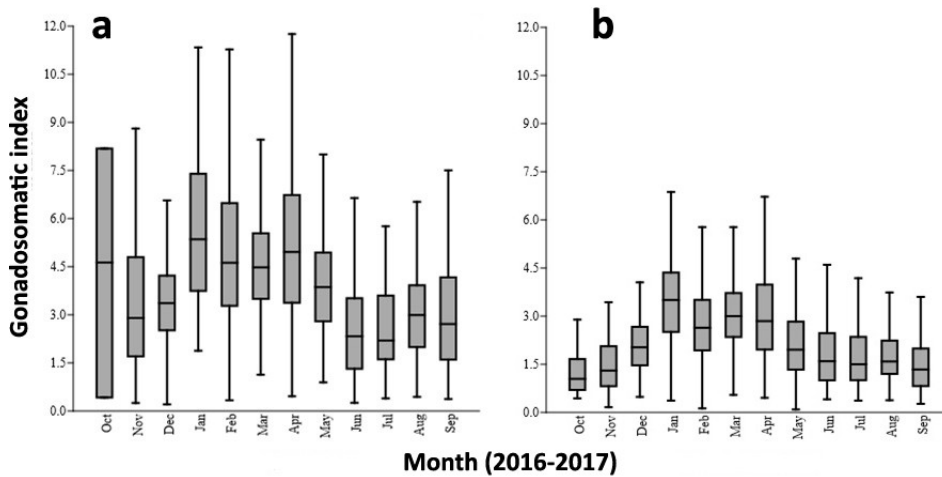


FIGURE 4 Monthly variation in gonadosomatic index in female (a) and male (b) *Chirostoma arge* in Lake Chapala, Mexico, from October 2016 to September 2017.

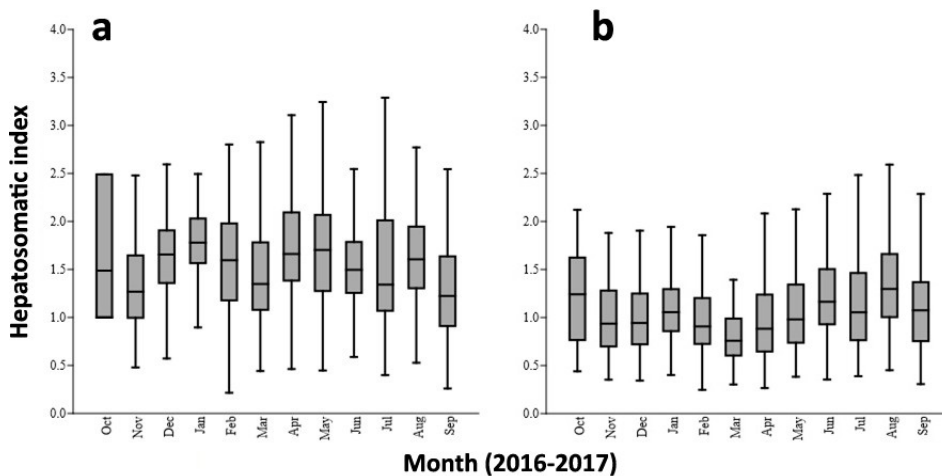


FIGURE 5 Monthly variation in the hepatosomatic index in female (a) and male (b) *Chirostoma arge* in Lake Chapala, Mexico, from October 2016 to September 2017.

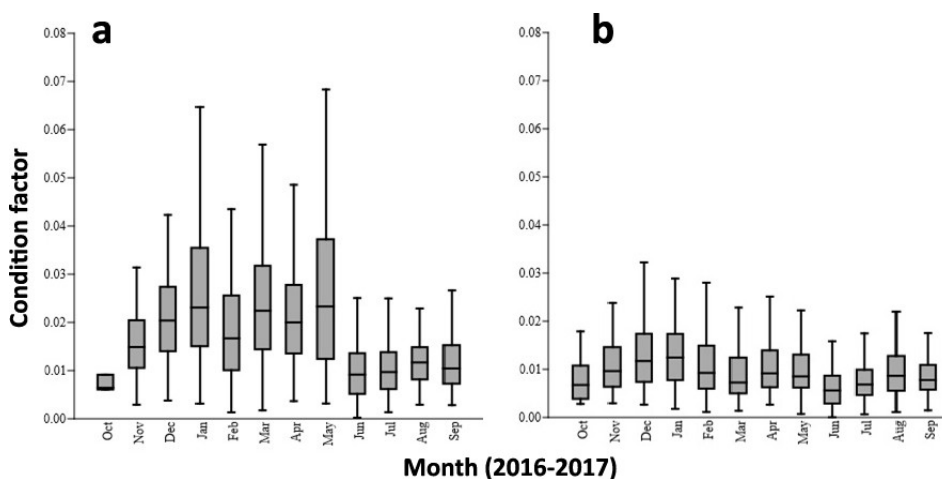


FIGURE 6 Monthly variation in condition factor in female (a) and male (b) *Chirostoma arge* in Lake Chapala, Mexico, from October 2016 to September 2017.

4 | DISCUSSION

Fishing for silversides in Lake Chapala is multispecies, including specimens of *Chirostoma chapalae*, *C. labarcae*, *C. contrerasi*, *C. consocium*, *C. jordani* and *C. arge*, the first three endemic to the Lerma-Chapala basin and the last three to the central plateau of Mexico, which has a wider geographical distribution (Lyons *et al.* 1998; Miller *et al.*

2005; Arredondo-Vargas *et al.* 2013; Gomez Vanega *et al.* 2022). The study by Gomez Vanega (2018) reported *C. arge* and *C. jordani* as the most frequent and abundant species between 2016 and 2017 in silverside catches in Lake Chapala. This finding indicates a replacement of silverside species in Lake Chapala on an interannual scale, as reported by other authors. Guzmán *et al.* (1995) re-

ported a higher frequency and abundance of *C. consocium* in the latter part of the 1980s (1985–1989), while Kelly (2005) reported *C. jordani*, *C. consocium* and *C. chapalae* as frequent and abundant between 1998 and 1999. Similarly, Moncayo-Estrada *et al.* (2011b) reported the presence of *C. jordani*, *C. labarcae* and *C. consocium*

during a period of lower water volume in 2000–2001 and a period of recovery in 2005. Due to the lack of studies on the reproductive activity of *C. arge*, a comparison is made with the reproduction aspects of other species of silver-side in the Arge group, such as *C. jordani* and *C. consocium*.

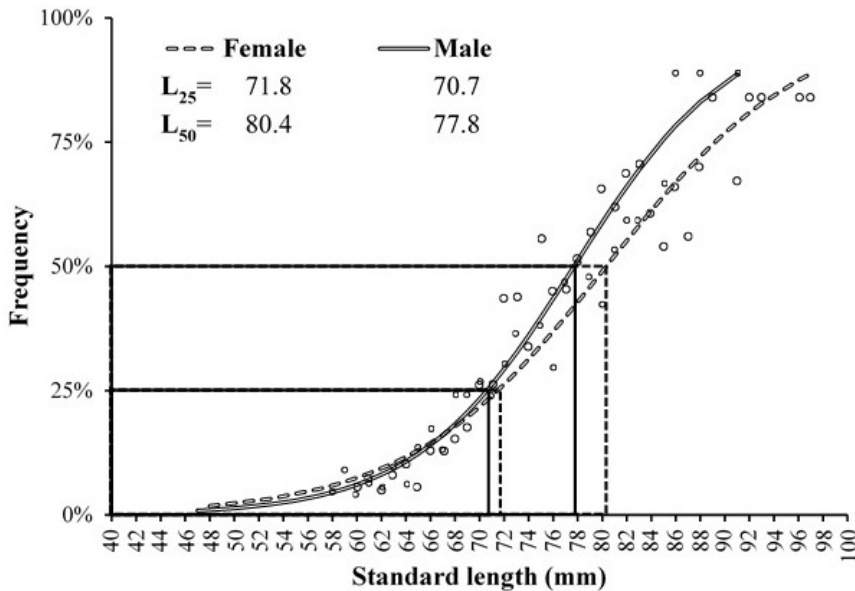


FIGURE 7 Minimum (L_{25}) and mean (L_{50}) standard length at estimated sexual maturity in female and male *Chirostoma arge* in Lake Chapala, Mexico, from October 2016 to September 2017.

TABLE 2 Potential fecundity, standard length and total weight in female *Chirostoma arge* for the different sampling sites (n : number of individuals, Min: minimum, Max: maximum and SD: standard deviation).

Site	n	Potential fecundity		Standard length (mm)		Total weight (g)	
		Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)
Ajijic	10	1240-2885	1985 (± 557)	78.5-88.8	81.6 (± 3.25)	5.47-7.32	6.23 (± 0.66)
Chapala	3	962-2801	1804 (± 929)	72.2-86.7	80.3 (± 7.35)	3.81-8.22	5.99 (± 2.20)
Mismaloya	15	1112-3384	2002 (± 667)	72.4-97.9	83.9 (± 7.58)	4.47-11.04	6.50 (± 1.66)
Petatán	18	1063-2552	1528 (± 426)	68.2-83.8	75.2 (± 4.54)	3.98-6.90	4.99 (± 0.87)
San Luis Soyatlán	15	988-2395	1621 (± 352)	73.2-89.9	82.5 (± 4.81)	4.66-8.23	6.68 (± 1.11)
San Pedro de Itzcán	6	1259-3636	1997 (± 879)	72.8-80.9	76.8 (± 2.93)	4.06-6.20	4.86 (± 0.82)
Total	67	962-3636	1778 (± 582)	68.2-97.9	80.1 (± 6.20)	3.81-11.04	5.92 (± 1.36)

Guzmán *et al.* (1995) suggested that *Chirostoma* spp. populations in Lake Chapala consist mainly of males. These authors reported that, in the 1980s (1983–1989), the population of male *C. consocium* in this lake was more abundant than that of females. This ratio can vary considerably in populations of the same species across different years due to fluctuations in food availability (Nikolsky 1963), breeding seasons, differential mortality, fishing gear selectivity and differential habitat occupation by males and females (Vazzoler 1996). Environmental factors, particularly temperature, as well as sex segregation in certain areas of the reservoir, also influence sex determination (Conover and Heins 1987; Figueroa-Lucero *et al.* 2003; Ibañez *et al.* 2008). The sex ratio at sampling sites

during the 2016–2017 annual cycle was skewed toward males in general, although with some variations across months and sampling sites.

Analysis of gonadal maturity stages indicated that a minimal proportion of females and males are reproductively active on a continuous basis. This pattern coincides with the findings of several authors, such as Navarrete (2000) for *C. jordani* in reservoirs of the State of Mexico, and Guzmán *et al.* (1995) for *C. consocium* in Lake Chapala. Similar reproductive behavior is widespread across various vertebrate and invertebrate groups in tropical latitudes, where environmental factors such as temperature remain relatively constant with only minor annual fluctuations (King 1995). However, certain tropical

species display brief periods or synchronous peaks in spawning (King 1995; Sparre and Venema 1997). In *C. arge*, the events of peak gonadal development (stage IV), spawning (stage V) and the resting period (stages I, II and III) are well defined, with spawning occurring from March to April and gonadal rest extending from June to October. This pattern of reproductive activity coincides with the study by Olvera *et al.* (2009) on *C. jordani* in the Xochimilco reservoir (Mexico City), where peak maturity and spawning were found to occur from January to May.

Likewise, Ibáñez *et al.* (2008) and Navarrete-Salgado (2017) reported peak reproduction, maximum maturity and spawning in the Metztitlán lagoon (Hidalgo) from April to July and again between November and December. Additionally, Navarrete (2000) and Navarrete and Fernández (1995) recorded reproductive periods from March to September in the Macuá reservoir (State of Mexico). For Lake Chapala, previous reports of spawning periods are limited to *C. jordani* (Aguilera-Taylor *et al.* 2002) and *C. consocium* (Guzmán *et al.* 1995) (Table 3).

TABLE 3 Sex ratio, breeding season and average size (L50) at sexual maturity for *Chirostoma arge* and *C. jordani* estimated by different authors. M = male; F = female.

Chirostoma spp.	Sex ratio (F : M)	Season of peak maturity and spawning	L ₅₀		Site	Source
			F	M		
<i>C. arge</i>	1.3 : 0.7	Mar - Apr	80.4	77.8	Chapala	Present study
<i>C. jordani</i>		Mar - Aug			Macuá, Estado de México	Navarrete (2000)
	3 : 1	Mar - Sep			Macuá, Estado de México	Navarrete & Fernández (1995)
	1 : 2	Apr - Jul Nov - Dec	43		Meztitlán, Estado de Hidalgo	Ibáñez <i>et al.</i> (2008)
	1 : 1.5	Jan - May	48	55	Xochimilco, Ciudad de México	Olvera <i>et al.</i> (2002)
		Winter (Dec - Mar)			Chapala, Estado de Jalisco	Aguilera-Taylor <i>et al.</i> (2002)
		May - Jul and Nov			Meztitlán, Estado de México	Navarrete-Salgado (2017)

The metabolic conditions determined by estimating the gonadosomatic index (GSI) and condition factor (K_n) in female and male *C. arge* showed a similar pattern during the study period, with significant increases from January to May followed by a period of rest and/or physiological restoration from June to September. However, clear discrepancies emerged between indicators, as the increase in the hepatosomatic index (HSI) began in October-November and subsequently declined from February onward, when GSI and K_n were already registering maximum values through May. This inverse relationship suggests that, as the gonad develops to reach maximum maturity, energy stored in somatic tissues such as the liver and muscles is mobilized to support gonadal maturation and spawning. However, they recover again in the same way that the HSI increases again, following this trend throughout the year (Martín-Cruz 2013), as observed in both sexes of these species in Lake Chapala. HSI is related to lipid and glycogen reserves, which vary depending on the balance between deposits from intake or transfer from other reserve organs and expenditure due to gonadal demand (Love 1970). In the case of males, the fact that the HSI tends to remain stable and vary in some months compared to females may be due to the fact that males use less energy for reproduction than females, since the pro-

cess of oogenesis involves greater nutrient demands due to the size of the gametes and the presence of vitellus (Martín-Cruz 2013). The aforementioned results are consistent with those obtained by Olvera *et al.* (2009) for *C. jordani* from Xochimilco, who indicate that HSI increases at the onset of the breeding season and declines at its conclusion. According to Bagenal (1957), the relative condition factor (K_n) reflects a complex combination of physiological and environmental influences, serving in the literature as a measure of various biological traits that fluctuate predictably across seasonal feeding and reproductive cycles. In *C. arge*, significant monthly variation in K_n is likely linked to its extended spawning period, driven by the substantial energetic cost of gamete release. Following spawning, K_n increases as metabolic functions normalize (Vazzoler 1996), with peak values reflecting fully mature individuals in the population. This pattern contrasts with the findings of Ibáñez *et al.* (2008) for *C. jordani* in Metztitlán Lagoon, where K_n showed no clear alignment with reproductive events.

The mean standard length at first maturity (SL_{50}) can vary within a population, as it is determined by genetic, physiological and environmental factors (Nikolsky 1963; Wootton 1990; Tyler and Sumpter 1996). In *C. arge*, SL_{50} was higher in females than in males, indicating that males

reach sexual maturity at a smaller size and earlier age. Variation in maturity size within and between populations is widely documented and influenced by growth and mortality rates, species longevity, population density, food availability and temperature (Wootton 1990; Tyler and Sumpter 1996). The body sizes recorded in the present study exceed those previously reported for *C. arge*, with a mean SL of 80.1 mm and a maximum SL of 97.9 mm recorded along the southeastern shore of Lake Chapala. By comparison, Guzmán *et al.* (1995) reported a maximum SL of only 65 mm. Consequently, these findings represent the largest recorded mean and maximum standard lengths for this species in Lake Chapala.

This study provides the first estimate of potential fecundity for *C. arge*, revealing marked variation in fertility across sampling sites, body length and weight. These values align with ranges reported for other *Chirostoma* species in a reservoir in the State of Mexico, such as 564–1102 oocytes per female by Hernández (1993) and 745–1870 oocytes by Navarrete (2000). They are also comparable to findings by Olvera *et al.* (2009) in Lake Xochimilco (Mexico City), who reported 143–952 oocytes per female, a lower potential fecundity than that observed in our findings. Overall, *C. arge* exhibited a higher mean potential fecundity (1778 oocytes per female) than previously recorded for related species. Furthermore, a positive relationship between body size, weight and egg count was evident, with females at four sampling sites displaying larger sizes and weights alongside higher oocyte counts. Fecundity can vary across populations, geographical regions and years, driven by fluctuations in environmental conditions as well as food quantity and quality (Wootton 1990). Alterations in any of these factors can affect egg size and batch size, which are strongly correlated with maternal length and weight, as larger and heavier females produce greater numbers of eggs (Duarte and Alcaraz 1989; Winemiller and Rose 1992). The higher fecundity observed in the present study contrasts with values reported by Arredondo-Vargas *et al.* (2013), who recorded a lower potential fecundity of 600 eggs per female across several *Chirostoma* species in Lake Chapala. Similarly, Guzmán *et al.* (1995) reported a potential fecundity of 800–1100 eggs for a 10 g female of *C. consocium* in Lake Chapala.

5 | CONCLUSIONS

Biological data for *C. arge* and other *Chirostoma* species across Lake Chapala and the Mexican Central Plateau remain limited. This study provides baseline information on the reproductive biology of the lake's most abundant silverside species during the 2016–2017 annual cycle. Key findings include a persistent male-biased sex ratio, a primary peak in maturity and spawning from January to May, a smaller mean standard length at first maturity in

males than in females and the first potential fecundity estimates for the species. These data provide essential biological baselines for fisheries management authorities in western Mexico to support the sustainable conservation and commercial exploitation of silverside stocks in Lake Chapala.

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ETHICAL APPROVAL

All fish specimens were obtained directly from commercial landings; no live animals were handled or subjected to experimental procedures. Consequently, formal ethical approval was not required for this study. All national and institutional regulations governing biological sampling from commercial fisheries were strictly observed.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHORS' CONTRIBUTION

HDGV: Conceptualization, methodology, formal analysis, investigation, data curation, visualization, writing – original draft. ELU: Conceptualization, formal analysis, writing – review & editing, supervision, project administration, funding acquisition.

AI-USE STATEMENT

The authors take full responsibility for the accuracy and scientific content of the research. AI tools (OpenAI) were used solely for language improvement and grammar correction.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author, ELU.

REFERENCES

- Aguilar JF, Navarrete N (1996) Crecimiento, condición y mortalidad del charal *Chirostoma humboldtianum* (Atheriniformes: Atherinidae) en México. *Revista de Biología Tropical* 44(3B): 573–578.
- Aguilera-Taylor I, Segura-García V, Moncayo-Estrada R, Escalera C (2004) Análisis comparativo de la repro-

- ducción en tres especies de charales (*Chirostoma jordani* Woolman 1894; *Chirostoma consocium* Jordan and Hubbs 1919 y *Chirostoma labarcae* Meek, 1902) del lago de Chapala, México. Memoria del VIII Congreso Nacional de Ictiología, Puerto Ángel, Oaxaca, Mexico. 33 pp.
- Arancibia H, Cubillos L, Remmaggi J, Alarcón R (1994) Determinación de la talla de primera madurez sexual y fecundidad parcial en la sardina común, *Strangomera bentincki* (Norman, 1936), del area de Talcahuano, Chile. *Biología Pesquera* 23: 11–17.
- Arredondo-Vargas E, Osuna-Paredes C, Meléndez-Galicia C, de Jesús-Avendaño C, Hernández-Montaña D (2013) Lago de Chapala, Michoacán y Jalisco. In: MT Gaspar-Dillanes, D Hernández-Montaña (Eds) *Pesquerías continentales de México* (pp. 35–52). Instituto Nacional de Pesca, Mexico City.
- Bagenal TB (1957) [Annual variations in fish fecundity](#). *Journal of the Marine Biological Association of the United Kingdom* 36(2): 377–382.
- Barba TJF (1990) Taxonomía, biología y ecología del languido *Scyaciium ovale* (Gunther) en areas del Pacífico Mexicano 1982–1983 (Teleostei: Bothidae). Master's Thesis. Facultad de Ciencias, UNAM, Mexico City. 111 pp.
- Barbour CD (1973) The systematics and evolution of the genus *Chirostoma*, Swainson (Pisces, Atherinidae) Mexico. *Tulane Studies in Zoology and Botany* 19(3): 97–141.
- Barriga-Sosa IDLA (2003) Estudios sobre la variabilidad morfológica y de genética molecular en el género *Chirostoma Iztapalapa*, México. In: Historia y avances de cultivo del pescado blanco. Instituto Nacional de Pesca, SAGARPA, Mexico City. pp. 107–123.
- Clark FN (1928) The weight-length relationship of the California sardine (*Sardina caerulea*) at San Pedro. *Fish Bulletin* 12: 22–44.
- CONAPESCA (2025) Anuario estadístico de acuicultura y pesca. Dirección General de Planeación, Programación y Evaluación de la Comisión Nacional de Acuicultura y Pesca (CONAPESCA), Mazatlán, Sinaloa. 341 pp.
- Conover DO, Heins SW (1987) [Adaptive variation in environmental and genetic sex determination in a fish](#). *Nature* 326(6112): 496–498.
- Contreras-Balderas S, Ruíz-Campos G, Schmitter-Soto JJ, Díaz-Pardo E, Contreras-McBeath T, ... Lyons J (2008) [Freshwater fishes and water status in Mexico: a country-wide appraisal](#). *Aquatic Ecosystem Health and Management* 11(3): 246–256.
- DOF (2010) [Norma Oficial Mexicana NOM-059-SEMARNAT-2010](#). Protección ambiental-especies nativas de México de flora y fauna silvestres-categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-lista de especies en riesgo. Secretaría de Medio Ambiente y Recursos Naturales, Gobierno Federal de México, Mexico City.
- Duarte CM, Alcaraz M (1989) [To produce many small or few large eggs: a size-independent reproductive tactic of fish](#). *Oecologia* 80(3): 401–404.
- Echelle AA, Echelle AF (1984) Evolutionary genetics of a species flock: atherinid fishes on the mesa central of México (pp. 93–110). In: AA Echelle, I Komfield (Eds) *Evolution of fish species flocks*. University of Maine, Orono.
- Echeverría TW (1987) Thirty-four species of California rockfishes: maturity and seasonality of reproduction. *Fishery Bulletin* 85(2): 229–250.
- Espinosa H, Castro-Aguirre JL, González-Acosta AF (2011) Los peces costeros. In: Ambiente, biología, sociedad, manejo y legislación de sistemas costeros mexicanos. Plaza y Valdés Editores, Mexico City. pp. 181–207.
- Estrada F, Flores ET, Michel JER (1983) Lago de Chapala, investigación actualizada. Instituto de Geografía y Estadística, Instituto de Astronomía y Meteorología, Universidad de Guadalajara, Jalisco, Mexico. 67 pp.
- Figueroa-Lucero G, Paulo-Maya J, Hernández-Rubio MC (2003) Retrospectiva y avances en el conocimiento de la biología y ecología de los charales y peces blancos del género *Chirostoma* (Atheriniformes: Atherinopsidae) ENCB-IPN (pp. 29–48). In: Rojas-Carrillo PM, D Fuentes-Castellanos (Eds) *Historia y avances de cultivo del pescado blanco*. Instituto Nacional de la Pesca, SAGARPA, Mexico City.
- Filonov AE, Tereshchenko IE, Monzón CO (2001) Hydro-meteorology of Lake Chapala (pp. 151–182). In: Hansen AM, van Afferden M (Eds) *The Lerma-Chapala watershed: evaluation and management*. Springer US, Boston, Massachusetts, USA.
- Froese R, Pauly D (2025) [FishBase](#). World Wide Web Electronic Publication. Accessed on Feb 09, 2026.
- Gomez Vanega HD (2018) Estructura poblacional y actividad reproductiva del charal (Atherinopsidae: *Chirostoma*) en el Lago de Chapala, México. Master's Thesis. Centro Universitario de Ciencias Biológicas y Agropecuarias, Universidad de Guadalajara, Jalisco, Mexico. 82 pp.
- Gomez Vanega HD, Espino-Barr E, López Uriarte E (2022) [Population analysis of smallmouth silverside, *Chirostoma chapalae* Jordan & Snyder, 1899 \(Atherinopsidae\), an endemic fish in Lake Chapala, Mexico](#). *Fisheries and Aquatic Life* 30(1): 44–56.
- Guzmán AM (1989) La fauna acuática de la nueva galicia. Instituto de Limnología, Universidad de Guadalajara, Jalisco, Mexico. 8 pp.
- Guzmán AM, Galaviz SS, Morelos MGL (1995) Ciclos reproductivos (pp. 93–107). In: La pesca en lago de Chapala: hacia su ordenamiento y explotación racional. Instituto de Limnología, Universidad de Gua-

- dalajara, Jalisco, Mexico. 302 pp.
- Guzmán-Arroyo M (1995) La pesca en el Lago de Chapala: hacia un ordenamiento y explotación racional. Comisión Nacional del Agua, Universidad de Guadalajara, Jalisco, Mexico. 302 pp.
- Guzmán-Arroyo M (2003) Chapala: una crisis programada. Grupo Parlamentario del PVEM, Cámara de Diputados LVIII Legislatura del H. Congreso de la Unión, Mexico City. 308 pp.
- Guzmán-Arroyo M, Ortiz-Martínez JM (1995) Distribución espacial. In: La pesca en lago de Chapala: hacia su ordenamiento y explotación racional. Instituto de Limnología, Universidad de Guadalajara, Jalisco, Mexico. 302 p.
- Hernández OF (1993) Evaluación de algunos aspectos de alimentación y reproducción del charal *Chirostoma jordani* (Woolman) en el embalse Macuá, Estado de México. Bachelor's Thesis. ENEP-Iztacala, UNAM, Mexico City.
- Hunter JR, Macewicz BJ, Lo NCh, Kimbrell CA (1992) Fecundity, spawning, and maturity of female Dover sole *Microstomus pacificus*, with an evaluation of assumptions and precision. Fishery Bulletin 90(1): 101–128.
- Ibáñez AL, García JLC, Torres RO (2008) Aspectos reproductivos de una población de charal *Menidia jordani* (Woolman) del Lago de Metztitlán, Hidalgo. Hidrobiológica 18(1): 1–9.
- INE (2003) Diagnóstico biofísico y socio-económico de la cuenca Lerma-Chapala-Santiago. Resumen ejecutivo. Dirección de Manejo Integral de Cuencas Hídricas, Instituto Nacional de Ecología, Mexico City, Mexico. 32 pp.
- Introzzi AR, Introzzi G (1986) Estudio de las concentraciones de los ácidos nucleicos (RNA, DNA) en músculo blanco e hígado de la lisa (*Mugil brasiliensis*) a lo largo de sus periodos de reposo y maduración gonadal. Revista de Investigación y Desarrollo Pesquero 6: 117–129.
- IUCN (2018) [The IUCN red list of threatened species](#). International Union for Conservation of Nature. Accessed on May 19, 2025.
- Kelly JP (2005) Trophic resource partitioning among nine sympatric congeners in an ancient tropical lake. Master's Thesis. Baylor University, Waco, Texas, USA.
- King M (1995) Fisheries biology, assessment and management. Fishing News Books, Oxford, UK. 341 pp.
- Lévêque C (1997) Biodiversity dynamics and conservation: the freshwater fish of tropical Africa. Cambridge University Press, Cambridge, UK. 438 pp.
- Lind OT, Davalos-Lind LO (2002) [Interaction of water quantity with water quality: the Lake Chapala example](#). Hydrobiologia 467(1): 159–167.
- Love RM (1970) The chemical biology of fishes. Academic Press, London. 547 pp.
- Lyons J, González-Hernández G, Soto-Galera E, Guzmán-Arroyo M (1998) [Decline of freshwater fishes and fisheries in selected drainages of west-central Mexico](#). Fisheries 23(4): 10–18.
- Martín-Cruz RM (2013) Ciclo reproductivo de *Euthynnus alletteratus* (Rafinesque, 1810) en el suroeste del Golfo de México. Master's Thesis. Universidad Veracruzana, Xalapa, Veracruz. 80 pp.
- Martínez-Palacios CA, Ríos-Durán MG, Campos-Mendoza A, Toledo-Cuevas M, Ross LG (2002) Avances en el cultivo del pescado blanco de Pátzcuaro *Chirostoma estor estor*. In: Avances en Nutrición Acuicola (pp. 336–351). Memorias del VI Simposio Internacional. Cancún, Quintana Roo, Mexico.
- Miller RR, Minckley WL, Norris SM (2005) Freshwater fishes of México. The University of Chicago Press, Chicago. 490 pp.
- Miller RR, Minckley WL, Norris SM (2009) Peces dulceacuicolas de México. CONABIO, SIMAC, ECOSUR, Consejo de Peces del Desierto, Mexico City. pp. 180.
- Moncayo-Estrada R, Escalera-Gallardo C, Lind OT (2011b) [Spatial patterns of zooplanktivore *Chirostoma* species \(Atherinopsidae\) during water-level fluctuation in the shallow tropical Lake Chapala, Mexico: seasonal and interannual analysis](#). Neotropical Ichthyology 9(4): 815–824.
- Moncayo-Estrada R, Lind OT, Escalera-Gallardo C (2011a) [Trophic interactions among sympatric zooplanktivorous fish species in volume change conditions in a large, shallow, tropical lake](#). Neotropical Ichthyology 9(1): 169–176.
- Morelos-López G, Guzmán-Arroyo M (1995) Ictiofauna del Lago. In: La Pesca en el Lago de Chapala: Hacia su Ordenamiento y Explotación Racional. Instituto de Limnología, Universidad de Guadalajara, Jalisco, Mexico. pp. 93–107.
- Navarrete SNA (2000) Temporada reproductiva y fecundidad de dos especies de charal *Chirostoma jordani* y *C. humboldtianum* del estado de Mexico. Ejercicio Calificador, UNAM, Mexico City. In: Paulo J (Ed) Situación Actual del Conocimiento de la Biología del Género *Chirostoma* Swainson (Pisces: Atherinopsidae). Escuela Nacional de Ciencias Biológicas, IPN, Mexico City.
- Navarrete SNA, Cházaro OS (1992) Espectro trófico del charal *Chirostoma humboldtianum* (Valenciennes) Pisces Atherinidae del embalse San Felipe Tiacaque, Estado de México. Revista de Zoología 3: 28–34.
- Navarrete SNA, Fernández GE (1995) Reproducción de *Chirostoma jordani* en el embalse Macua, Estado de México. Memorias del XIII Congreso Nacional de Zoología. Morelia, Michoacán, Mexico.
- Navarrete-Salgado NA (2017) *Chirostoma* (Menidia): ecología y utilización como especie de cultivo en es-

- tanques rústicos. BIOCOT Biología, Ciencia y Tecnología 10(37–39): 736–748.
- Nikolsky G (1963) The ecology of fishes. Academic Press, New York. 352 pp.
- Olvera BYM, Gómez-Márquez JL, Peña-Mendoza B, Gaspar-Dillanes MaT, Pérez C (2009) Reproductive biology of *Menidia jordani* (Atheriniformes: Atherinopsidae) in Xochimilco Lake, Mexico. Ciencia Pesquera 17(2): 65–75.
- Rojas-Carrillo PM, Fernández-Méndez JI (2006) La pesca en aguas continentales (pp. 49–68). In: Pesca, acuicultura e investigación en México. Comisión de Pesca, Cámara de Diputados, Mexico City.
- Saunders DL, Meeuwig JJ, Vincent ACJ (2002) [Freshwater protected areas: strategies for conservation](#). Conservation Biology 16(1): 30–41.
- SigmaStat (2007) SigmaStat for Windows, Version 3.5. Aspire Software International, Ashburn, VA, USA.
- Soto-Galera E, Díaz-Pardo E, López-López E, Lyons J (1998) [Fish as indicators of environmental quality in the Río Lerma Basin, México](#). Aquatic Ecosystem Health and Management 1(3–4): 267–276.
- Sparre P, Venema S (1997) Introducción a la evaluación de recursos pesqueros tropicales. Parte 1. Manual (Documento Técnico de Pesca 306. 1 Rev. 2). FAO, Rome, Italy.
- Torres-Orozco R, Pérez-Hernández MA (2011) Los peces de México: una riqueza amenazada. Revista Digital Universitaria 12(1): 1–15.
- Tyler CR, Sumpter JP (1996) [Oocyte growth and development in teleosts](#). Reviews in Fish Biology and Fisheries 6(3): 287–318.
- Vazzoler AEAM (1996) Biología da reprodução de peixes teleósteos: teoria e prática, São Paulo, Brazil. 169 pp.
- Vega-Salazar MY (2003) Situación de los peces dulceacuícolas en México. Ciencias 72: 20–30.
- Winemiller KO, Rose KA (1992) [Patterns of life-history diversification in North American fishes: implications for population regulation](#). Canadian Journal of Fisheries and Aquatic Sciences 49(10): 2196–2218.
- Wootton RJ (1990) Ecology of teleost fishes. Fish and Fisheries Series 1. Chapman and Hall, London, 404 pp.



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