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RESEARCH ARTICLE

Population analysis of smallmouth silverside, *Chirostoma chapalae* Jordan & Snyder, 1899 (Atherinopsidae), an endemic fish in Lake Chapala, Mexico

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Abstract. A sample was analyzed of 1,129 specimens of *Chirostoma chapalae* from Lake Chapala, Mexico obtained from catches of local fishers between October 2016 and September 2017. Size frequency, length-weight relationships (LWRs), growth, mortality, exploitation rate, survival rate, and relative condition index were estimated. The LWRs showed negative allometric growth in females (b = 2.735) and isometric growth in males (b = 3.000). The SL_∞ was 9.20 cm in females and 8.94 cm in males, and the growth coefficient k ranged from 1.80 year^{-1} to 1.90 year^{-1}, and the t_0 from 0.119 to 0.113. Estimated total mortality (Z = 3.20 year^{-1}), natural mortality (M = 1.56 year^{-1}), and fishing mortality (F = 1.64 year^{-1}) values were higher in females. *C. chapalae* is at optimum, underexploited levels according to the exploitation rate (E = 0.42 year^{-1}). The SL at first capture (SLp_c) was 65.8 mm and the SL at retention (SLp_r) of the fishing gear was 62.4 mm. This indicates that more than 50% of the fish caught enter the fishery at a larger size. The condition factor (Kn) showed body robustness in fall and subsequent spawning from spring onwards. Our findings contribute to the future development of fisheries management strategies in the largest lake in Mexico.

Keywords: exploitation, fisheries, growth, Lake Chapala, mortality, silverside.

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Introduction

Lake Chapala, located in central western Mexico in the Lerma-Chapala-Santiago drainage basin, the highly significant because of its size and the population that inhabits its vicinity (Guzmán-Arroyo et al. 2003). Its fish fauna is diverse, with around 40 species recorded including native and introduced or exotic species (Miller et al. 2005, 2009). The families Atherinopsidae, Cyprinidae, and Goodeidae are notable because of the similar number of species of each that inhabit this natural lake. However, introduced species contribute the most to catches, and include tilapia (*Oreochromis* spp.), carp (*Cyprinus* spp.), and catfish (*Ictalurus* spp.). Native species of the family Atherinospsidae (CONAPESCA 2018) are also noted, and this is the most diverse genus of this family and is endemic to the Mesa Central of Mexico (Barbour 1973, Miller et al. 2005, 2009). The fishes of this genus have played an important role in the diet of the region's inhabitants since pre-Hispanic times (Aguilar and Navarrete 1996). The genus includes 18 species and six subspecies (Barbour 1973, Echelle and Echelle 1984, Rojas-Carrillo and Fernández-Méndez 2006), some of which are included on the list of threatened species (IUCN 2021). The genus Chirostoma is divided into two groups of silverside fishes by size–the Jordani group includes species with adult fishes larger than 20 cm in total length that are known as "white fish," and the smaller adult species of the Arge group, or small fish less than 12 cm in total length, known as *charal* (Aguilar and Navarrete 1996).

The smallmouth silverside, *Chirostoma chapalae* (Jordan and Snyder 1899), has an elongated, slender body and a small, oblique mouth. Its regular mouth exposes the teeth, which are small and placed in a narrow band on the premaxillaries and two or three lines in a wider band on the dentary teeth, but never on the vomer or palatines. The slender jaws project slightly. The pectoral fins are moderately long and pointed. The lateral line scales have canals and laciniate margins, though they are not as pronounced as in larger species, and the pre-dorsal region scales are moderately imbricate. The maximum recorded standard length is 8.7 cm (Morelos and Guzmán-Arroyo 1995). This species is found throughout the lake and is abundant in its northern and southern parts, especially during the spawning season, as are its sister species; this is associated with the substrate necessary for spawning such as rocks and plant roots (Guzmán-Arroyo and Ortiz-Martínez 1995). The season of maximum gonad maturity and spawning, which appears to be similar for the six sister species, is from January to April, although mature fish are reported throughout the year (Guzmán-Arroyo et al. 1995, Gomez-Vanega 2018). This species is a second order carnivore that feed on microcrustaceans, insects, amphipods, plant remains, organic matter, fish, non-insecta invertebrates, and rotifers, and the fish alternate among these prey types according to their size or age (Arriaga et al. 1995).

Catches of silverside in the Mesa Central of Mexico have for centuries been the basis of artisanal fishing for many families who depend almost exclusively on this resource (Martínez-Palacios et al. 2002, 2006). It is also one of the most important fisheries in Lake Chapala, and in 2016 production doubled from 2015 with 11,757 t, which even surpassed the production of previous years (CONAPESCA 2018). This lake is the largest natural water body in México with more than 90,000 ha on average, and it is of great climatic, economic, socio-cultural, and environmental relevance in the western region of the country (Guzmán-Arroyo and Merino-Nambo 1995, Curiel-Ballestero 2014), and it has also presented with continuous, drastic declines in water quantity and quality in recent decades as a result of human activities (de Anda and Shear 2001, Sánchez-Torres et al. 2018). Fishing catches have varied extremely with regard to occurrence and abundance since aquatic environments are being degraded at unprecedented rates, which has caused populations of some species to decline dramatically (Lyons et al. 1998, Arredondo-Vargas et al. 2013). As in most of Mexico's lakes, environmental problems in Lake Chapala include the introduction of non-native species (Contreras-Balderas et al. 2008), overfishing (Martínez-Palacios et al. 2002, 2006), water extraction for urban area needs (city of Guadalajara; CEA Jalisco 2019), habitat degradation by industrial and/or agricultural pollutants that, on the one hand, induce algal blooms that are harmful to the aquatic environment because of increased nutrients and that directly influence the structure and functioning of the Chapala basin lentic and lotic ecosystems, and, on the other hand, the presence of some metals such as mercury (Hg) that directly influence human health through the consumption of fish species (Alcocer and Escobar 1996, Rodríguez-Jorquera et al. 2017).

Little is known about *C. chapalae*, except for the information in studies by Gallardo-Cabello (1977), Guzmán-Arroyo (1995), and Elizondo-Garza and Fernández-Méndez (1996). Thus, the purpose of the present study was to analyse the size frequency, growth, condition, and mortality during the annual cycle of one of the three endemic species of *Chirostoma* spp. occurring in Lake Chapala. This information will contribute to the understanding of its population dynamics, which will help to establish fishery management strategies for sustainable exploitation.

Study area

Lake Chapala, located in central western Mexico (20°07' and 20°21' N and 102°40'45'' and 103°25'30'' W) in the Lerma-Chapala-Santiago drainage basin is highly significant because of its size (8.660 km^2) and the population that inhabits its vicinity (Guzmán-Arroyo et al. 2003) (Fig. 1). As in all warm tropical water bodies, the hydrological dynamics are determined by the rainy and dry seasons that directly influence the lake's water flow and that determine the water's physicochemical characteristics (Filonov et al. 2001).

Materials and methods

The *C. chapalae* samples were obtained from local fishers who used two types of fishing gears (DOF 2015). A gillnet consisted of a rectangle of 30 m or more in length and 2 m in drop, composed of three sections, the central one of which had a mesh opening of 5 to 7 cm and two ends with 1 cm mesh openings. This gear was set in the evening and retrieved in the morning after 8 h of exposure. The nasa, or *nasa charalera*, was a cylindrical structure built with a 2 m long corrugated rod, lined with nylon mesh made of either polyamide or polyethylene monofilament or multifilament, with minimum mesh size of 0.5-1.0 cm. Each fisher operated 20 *nasa charalera*, and they were set in areas called *ranchos charaleros* for approximately six months (January, February, May, June, and July) and were checked daily. The fish specimens were kept on ice (3-4°C) and transferred to laboratory, where they were washed with tap water, separated, and identified to

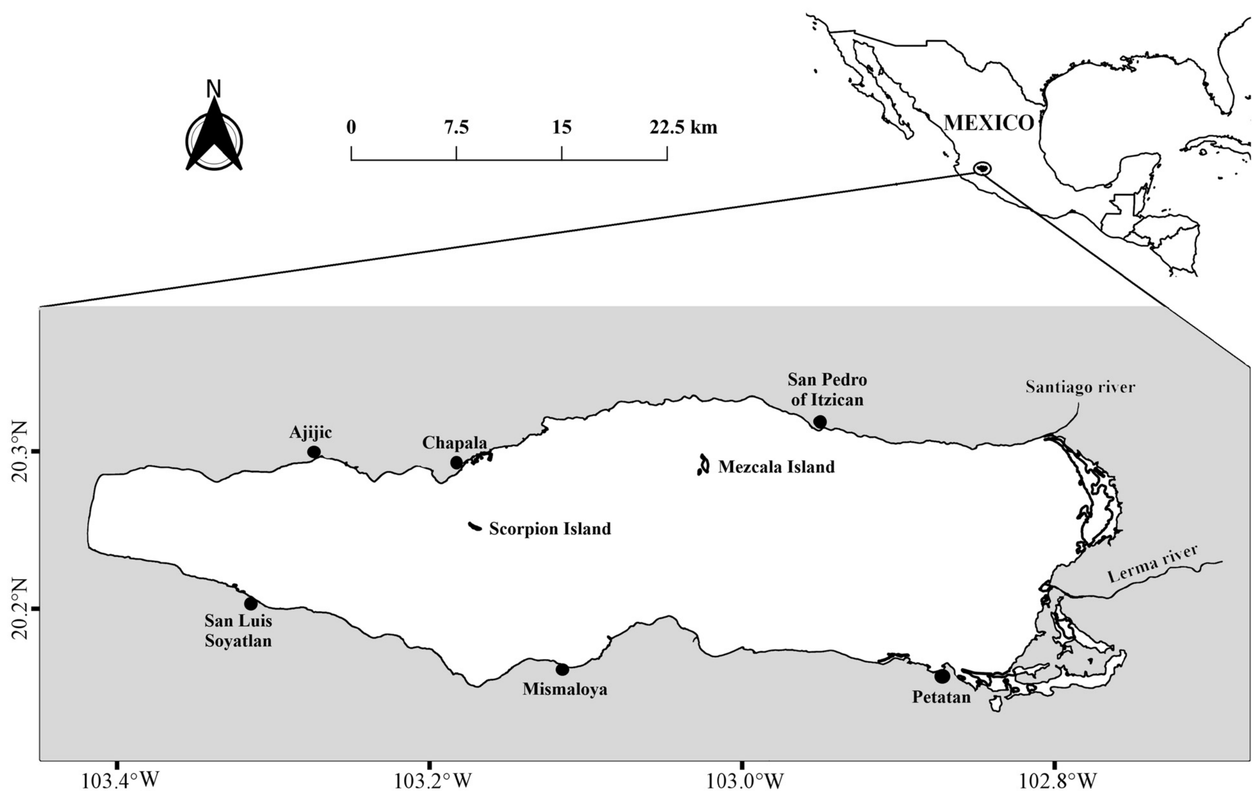

Figure 1. Location of landing areas and sampling sites in Lake Chapala, Mexico.

the species level according to the taxonomic guides by Barbour (1973) and Miller et al. (2005, 2009). The following were determined for each specimen: standard length (SL) to the nearest mm with a digital caliper; total weight (TW) to the nearest 0.0001 g on a digital scale; sex by macroscopic observation.

Normality and homoscedasticity were confirmed with the Kolmogorov-Smirnov and Bartlett's tests (Zar 2009). The data were also transformed to log base 10 (Log10) when they did not meet the Kolmogorov-Smirnov assumption of normality. The statistical significances of SL, TW, and condition index by sampling month and locality were determined with ANOVA when the data presented normal frequency distribution and with the non-parametric Kruskal-Wallis test (H) otherwise. When significant differences were found, Tukey's multiple comparisons test was applied. SigmaStat V3.5 (2007) was used for all statistical analyses.

Condition factor

The condition index was estimated monthly using Clark's (Froese 2006) formula to determine variation in fish body condition with the ratio $K = P/Lp^b \times 100$ where: P is total weight, Lp standard fish length, and *b* the constant. To determine significant differences among sites and months, the variation in K was analyzed using the non-parametric Kruskal-Wallis test.

Growth and length–weight relationship

The length-weight ratio was determined with the equation by Ricker (1975): $W = aSL^b$ where TW is the total weight in g, SL is the standard fish length in cm, a is the intersection with the axis of the ordinates, and *b* is the slope of the equation and the coefficient of growth. The isometric growth hypothesis (Ho: $b = 3$ and Ha: $b \neq 3$) was tested with Student's t test at a significance level of P = 0.05.

Growth estimations were based on monthly length frequency distributions at an interval of 0.3 cm with the software FiSAT II (version 1.2.2) (Gayanilo et al. 1996). The asymptotic length (SL_∞) and growth coefficient (k) were estimated by applying the ELEFAN I routine: t_0 was calculated according to Pauly's formula (Pauly 1979) in which $\log_{10}(-t_0) = -0.3922 - 0.2752 \log_{10} SL_\infty - 1.038 \log_{10} k$, where t_0 is the hypothetical age at which length is zero, SL_∞ is the average asymptotic length, and k is the coefficient of growth. To calculate longevity, Taylor's equation (Taylor 1958) was used: $A_{0.95} = t_0 + (2.996 / k)$, $A_{0.95}$ is the theoretical age limit or time required for a fish to reach 95% of its maximum length (SL_∞). The asymptotic weight was determined by the equation annotated by Csirke (1980): $W_\infty = aSL^b$ where W_∞ is the asymptotic weight, a and *b* the constants of the equation of the standard length-total weight ratio. Once SL_∞, W_∞, k, and t_0 were estimated, growth curves were calculated in standard length and weight, according to von Bertalanffy (1938): $SL = SL_\infty [1 - e^{-k(t + t_0)}]$; $W = W_\infty [1 - e^{-k(t + t_0)}]^b$. The phi (Ø'), or growth rate, is used to compare the growth performance of the species using the equation by Pauly and Munro (1984) $Ø' = \log_{10} k + 2 \log_{10} SL_\infty$.

Mortality

Total mortality (*Z*) was calculated using the Beverton and Holt (1959) equation: $Z = k (SL_\infty - L_{mean}) / (L_{mean} - L')$ where L_{mean} is the mean length and L´ is the smallest length of the catch. Natural mortality (M) was determined with Taylor's equation (Taylor 1960): $M = (2.996 / A_{0.95}) - t_0$ where $A_{0.95}$ is the age limit when an individual reaches a length corresponding to 95% SL_∞. Fishing mortality (F) was estimated using the Sparre and Venema (1997) equation: F = Z – M. Survival rate (S) was calculated by $S = e^{-Z}$ (Ricker 1975), and the exploitation rate (E) with the Gulland (1971) equation: E = F / Z.

Catch size

To obtain the recruitment size (SL_{25} or SLp_r) and first catch size (SL_{50} or SLp_c), which means that 25 or 50% of the class can be caught, the length frequency distribution was used, and the cumulative frequency was calculated from this.

Results

Population structure

Total of 1.129 specimens, 53.9% (n = 609) were female and 46.1% (n = 520) were male. Female mean SL (6.74 ± 0.50 cm) and mean TW (2.9 ± 0.6 g) values were higher than those of males (6.34 ± 0.44 cm) (Mann-Whitney U-test, n = 1129, P < 0.001), for which the following analyses were performed separately. In females the SL ranged from 5.36 to 8.93 cm and from 4.74 to 8.01 cm in males, with more frequent intervals between 6.23 and 7.13 cm in females and 5.93 to 6.83 cm in males (Fig. 2). In females the TW ranged from 1.5 to 6.5 g and from 0.9 to 4.6 g in males, with more frequent intervals between 2.5 to 3.5 g in females and 2.0 to 3.0 g in males (Fig. 3). The analysis of variance test indicated significant differences in male mean SL and TW values among months (ANOVA, F = 3.414, P = 0.001; F = 5.245, P = 0.001, respectively) and in mean TW among sampling sites (F = 2.369, P = 0.038). SL and TW values were higher in Ajijic and San Luis Soyatlán according to Duncan's multiple comparison test (P < 0.05). Female mean SL and TW values were significantly different among months (Kruskal-Wallis test, H = 79.270, P = 0.000; H = 85.114, P = 0.000, respectively), but mean TW values were similar among sampling sites (P > 0.05).

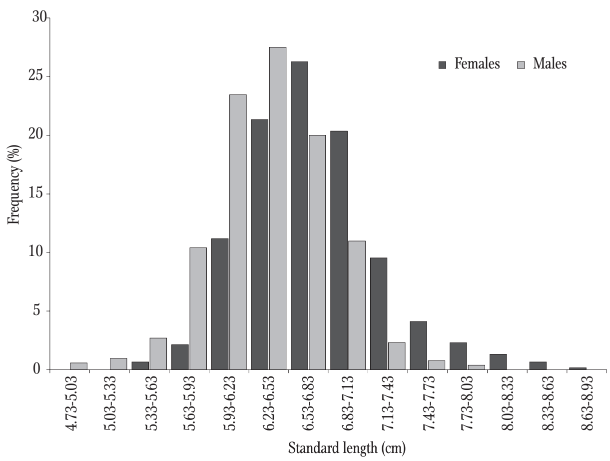

Figure 2. Standard length frequency distribution of *C. chapalae* in Lake Chapala, Mexico.

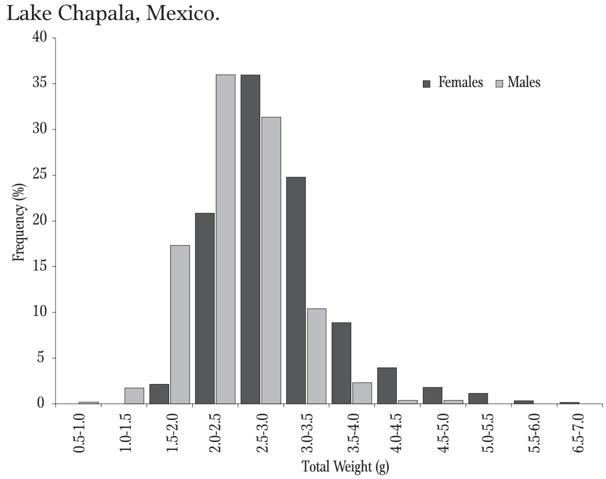

Figure 3. Total weight frequency distribution of *C. chapalae* in Lake Chapala, Mexico.

Length–weight relationship

The length-weight ratio of the total population of females and males was adjusted to a potential type model and expressed as: $TW = 0.0111SL^{2.918}$ (r^2 = 0.963, n = 1129), $TW = 0.0159SL^{2.735}$ (r^2 = 0.962, n = 609) and $TW = 0.0094SL^{3.000}$ (r^2 = 960, n = 520), respectively (Fig. 4). The type of growth for the all the samples (males + females) and the male population was isometric (P > 0.05), according to the Student's t test, but the female population showed negative allometric growth (P < 0.05). The coefficient (*b*) showed variations of isometry (*b* = 3), negative allometric (*b* < 3), and positive allometric (*b* > 3) in some months for both sexes.

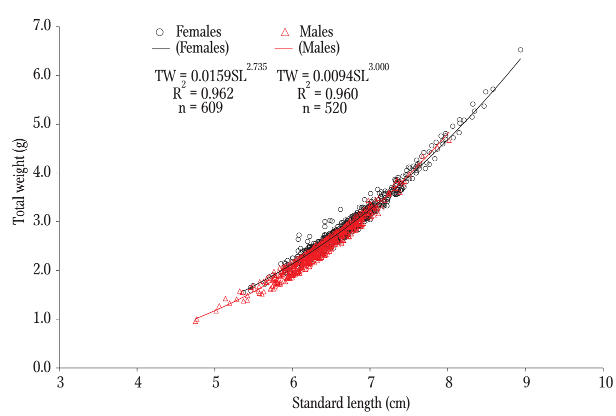

Figure 4. Morphometric relationships between standard length (SL) and total weight (TW) by sex for *C. chapalae* in Lake Chapala, Mexico. Circles = females; triangles = males.

Table 1
Growth parameters estimated with the equation von Bertalanffy, longevity, phi growth evaluation index, mortalities, survival rate, and exploitation rate of *C. chapalae* in Lake Chapala, Mexico

	Parameters										
	SL_∞	W_∞	k	t_0	$A_{0.95}$	Ø'	Z $year^{-1}$	M $year^{-1}$	F $year^{-1}$	E $year^{-1}$	S $year^{-1}$
Females	9.20	6.8	1.80	0.119	1.78	2.18	3.20	1.56	1.64	0.51	0.04
Males	8.94	6.7	1.90	0.113	1.69	2.18	3.02	1.65	1.37	0.45	0.04
Both sexes	9.29	7.4	1.83	0.117	1.75	2.19	2.74	1.59	1.15	0.42	0.06

Abbreviations: SL_∞, asymptotic length; W_∞, asymptotic weight; k, growth coefficient; t_0, hypothetical age; $A_{0.95}$, longevity; Ø', phi growth evaluation index; Z, total mortality; M, natural mortality; Z, fishing mortality; E, exploitation rate; S, survival rate.

Growth

The growth parameters estimated with length frequency analysis using ELEFAN I indicated that both sexes of *C. chapalae* were fast-growing (SL_∞ = 9.29 cm, k = 1.83, t_0 = 0.117), with growth rates slightly higher in males (SL_∞ = 8.94 cm, k = 1.90, t_0 = 0.113) than in females (SL_∞ = 9.20 cm, k = 1.80, t_0 = 0.119) (Table 1). By substituting the values of these parameters in the von Bertalanffy growth equation in length for the total population, is: $SL = 9.29\ [1 - e^{-1.83(t + 0.117)}]$ and in weight $TW = 7.4\ [1 - e^{-1.83(t + 0.117)}]^{2.918}$; in females the equation in length is $SL = 9.20\ [1 - e^{-1.80(t + 0.119)}]$ and by weight $TW = 6.8\ [1 - e^{-1.80(t + 0.119)}]^{2.735}$ (Fig. 5), whereas in males it is $SL = 8.94\ [1 - e^{-1.90(t + 0.113)}]$ and $TW = 6.7\ [1 - e^{-1.90(t + 0.113)}]^{3.000}$ (Fig. 6). Longevity ($A_{0.95}$) was higher in females than in males. While the growth assessment index (Ø') showed similar values for the two sexes, these were lower than those reported by other authors (Tables 1 and 3).

Mortality

The results of estimated total mortality (Z), natural mortality (M), fishing mortality (F), exploitation (E) and survival (S) rates in females, males, and the two sexes together are presented in Table 1. The exploitation rate was at an optimal level of utilization for the overall population and for males (E < 0.5), but for females it was slightly above the optimal (E = 0.5; E = 0.51), which indicated higher fishing mortality (F = 1.64) and total mortality (Z = 3.20).

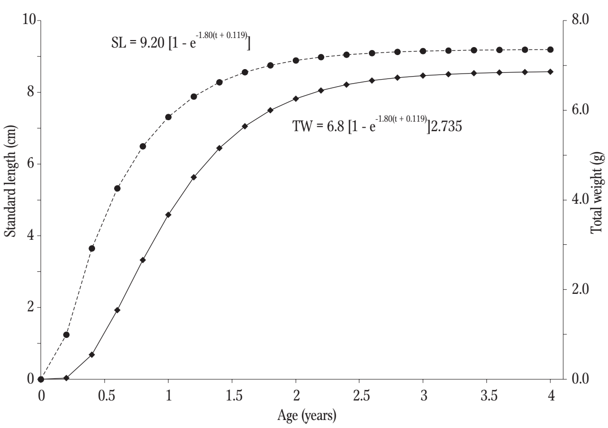

Figure 5. Von Bertalanffy growth curves in standard length (SL) and total weight (TW) in female *C. chapalae* in Lake Chapala, Mexico.

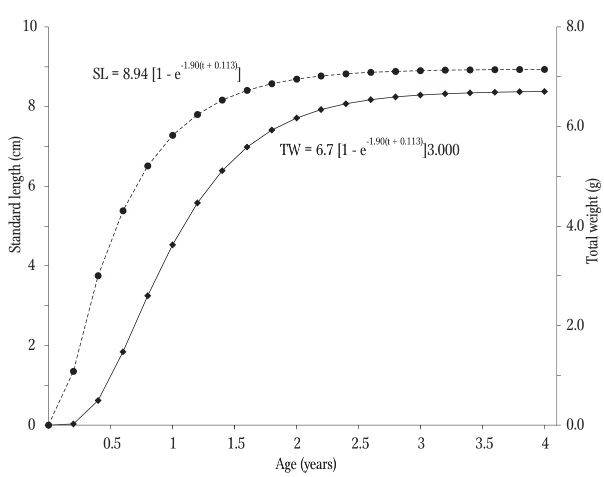

Figure 6. Von Bertalanffy growth curves in standard length (SL) and total weight (TW) in male *C. chapalae* in Lake Chapala, Mexico.

Catch size

C. chapalae standard length at first capture (SLp_c) was 65.8 mm, while the standard length at retention (SLp_r) of fishing gear was 62.4 mm (Fig. 7).

Condition factor (*Kn*)

The condition factor increased significantly from November 2016 to January 2017 (Kruskal-Wallis test, H = 362.105, P < 0.001), and then it decreased drastically beginning in February 2017 (Fig. 8). This suggested that between November and January the fish are storing biomass in preparation for gonad maturation and spawning in subsequent months from February to May.

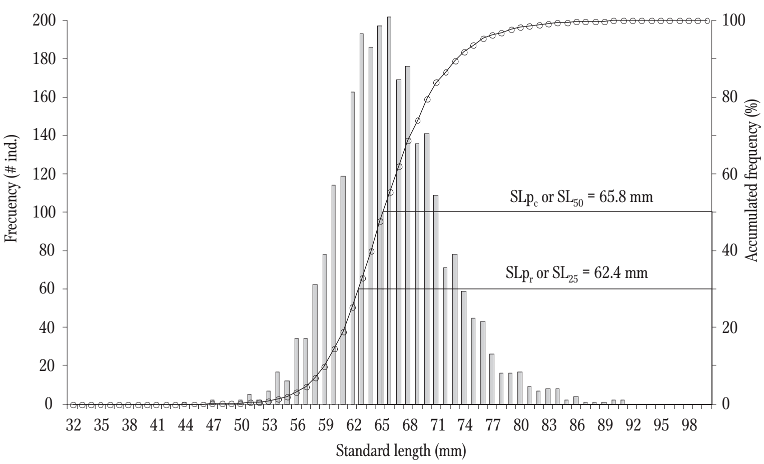

Figure 7. Frequency distribution of the standard length of *C. chapalae* in Lake Chapala, Mexico, indicating standard retention length (SLp_r or SL_{25}) and length of first capture (SLp_c or SL_{50}.

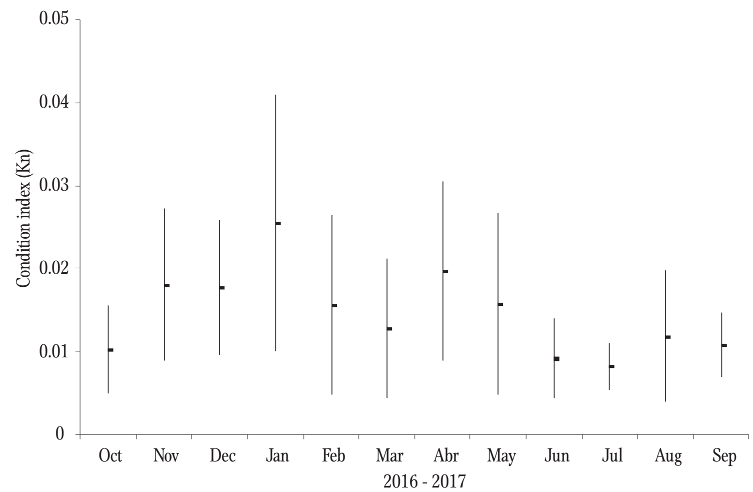

Figure 8. Monthly variation in the condition factor (Kn) of *C. chapalae* in Lake Chapala, Mexico, from October 2016 to September 2017.

Discussion

The *C. chapalae* length and weight relationships recorded in the current study differ from those reported by other authors for this species from Lake Chapala (Table 2) and were higher than those reported by Elizondo-Garza and Fernández-Méndez (1996). These researchers recorded specimens of *C. chapalae* between 4.0 and 10.0 cm total length (TL) from January 1991 to February 1993, while the specimens in the current study measured in excess of 10.0 cm TL (10.62 cm TL), and the average TW was above 2.7 g. Likewise, Morelos and Guzmán-Arroyo (1995) reported specimens smaller than 8.7 cm SL for this lake with catch data from 1988 to 1990, while the present study recorded an SL of 8.93 cm. Only Barbour (1973) indicated the presence of specimens of *C. chapalae* close to 9.3 cm SL, which was longer than the value reported in our study.

The average lengths (SL) and weights (TW) of *C. chapalae* in the present study were above those reported by other researchers in this natural lake. This was probably a reflection of environmental conditions and the lake level during the study period since the lake volume has recovered in recent years (CEA Jalisco 2019). This has had a direct influence on the biological diversity and productivity of the lake and is linked to the recovery of Chirostoma populations (Moncayo--Estrada et al. 2010), including that of *C. chapalae*. These differences are mainly associated with water dynamics in lake-reservoir-pond systems, or water levels, since environmental conditions vary annually and in individual years

Table 2
Summary of reported average standard lengths (cm) and minimums and maximums in species of the genus *Chirostoma* in Lake Chapala, México

	Mean	min	max	Study area	Researchers
Chirostoma chapalae	6.56	4.74	8.93	Chapala	Present study
			9.30		Barbour (1973)
		4.00*	10.00*	Chapala	Elizondo-Garza and Fernández-Méndez (1996)
			8.70	Chapala	Morelos-López and Guzmán-Arroyo (1995)
Chirostoma spp.		5.00	10.00	Chapala	Arredondo-Vargas et al. (2013)

Abbreviations: min – minimum, max – maximum, * – total length.

(Sánchez-Torres et al. 2018), the availability of food and the influences of human activities (Moncayo-Estrada et al. 2011a, 2011b), and also fishing gear selectivity, fishing pressure on resources, and catch sizes (Lyons et al. 1998).

The standard length (SL) and total weight (TW) average was higher in females than in males ($p < 0.05$), and similar results were reported by Elizondo-Garza and Fernández-Méndez (1996) for *C. chapalae* and by Guzmán-Arroyo et al. (1995) for *Chirostoma consoncium* in the same lake. This could be related to the temperature-dependent sex determination, which means that females are slightly larger than males because their earlier births give them a longer growing season (Conover 1984). This is also related to gender segregation in certain parts of the lake that was influenced by variations in food availability (Nikolsky 1963), reproduction times, and differences in fishing gear mortality and selectivity (Vazzoler 1996).

The absence of juveniles in the samples was associated with the selectivity of the fishing gear used since it controls the retention and escape of fish because the entrance, or the funnel, regulates the maximum fish size and the mesh coating limits the minimum size retained in the *nasa charalera*, in contrast gillnets only catch individuals larger than the mesh opening (Slack-Smith 2001) and the availability of the resource in the fishing area, because juveniles are found in growth zones until gonad development when they are recruited to the adult stock, i.e., there was probably spatial segregation among these fish (Lindeman 1989, Guzmán-Arroyo and Ortiz-Martínez 1995).

Based on the assumption that fish growth is generally isometric, which means that it is of equal magnitude in length with respect to weight (Ricker 1975, Froese 2006) at a value very close to 3, the length-weight ratio estimates indicated that this species exhibited negative allometric growth (female b = 2.73, both sexes b = 2.91), and only males exhibited isometric growth. This result is similar to what Elizondo-Garza and Fernández-Méndez (1996) reported for the same species in Lake Chapala at *a* constant of b = 1.16 (negative allometric), and that which Arredondo-Vargas et al. (2013) reported as allometric growth for Chirostoma spp. In contrast, Jiménez-Badillo and Gracia (1995) reported isometric growth in both sexes in populations of Chirostoma spp. (Jordani group) in Lake Patzcuaro, Michoacan State, Mexico. These similarities and differences could be linked to the fact that the constant b value varies among individuals of the same species and among species (Bagenal and Tesch 1978), among different localities, among seasonal cycles of feeding and reproductive processes, with variations in environmental conditions, sample size, and life cycles (Braga 1986, Lima-Junior et al. 2002). Because this fish goes through well-defined larval, fry, juvenile, and adult stages, they are characterized by differential growth in the proportion of length and weight in each of them (Jiménez-Badillo and Gracia 1995).

The findings reported in this study are the first data on *C. chapalae* asymptotic length (SL_∞) and

Table 3
Estimated growth parameters using the von Bertalanffy equation, Walford method (1946), Wetherall et al. (1987) and Gulland and Holt (1959), and phi growth evaluation index for species of the genus *Chirostoma* in lakes in México

	Parameters							
Species	SL_∞	K	t_0	W_∞	Ø'	Method	Study area	Author
C. chapalae	9.29	1.83	0.117	4.03	2.19	von Bertalanffy	Chapala	Present study
Chirostoma spp.	14.35	0.46					Chapala	Arredondo-Vargas et al. (2013)
Chirostoma spp.	14.54	0.12	0.251		3.25	Ford-Walford Wetherall et al. Gulland and Holt	Pátzcuaro, Michoacan	Jiménez-Badillo and Gracia (1995)

Abbreviations: SL_∞ asymptotic length; W_∞, asymptotic weight; K, growth coefficient; t_0, hypothetical age; $A_{0.95}$, longevity; Ø', phi growth evaluation index.

growth co-efficient (k) from this study area. The estimated asymptotic length (SL_∞) was 9.29 cm and the growth co-efficient (k) was 1.83 year^{-1} for both sexes of *C. chapalae*. Arredondo-Vargas et al. (2013) reported a higher L_∞ (14.35 cm) and a lower growth coefficient k (0.43 year^{-1}) than those estimated in the current study, but these differences stemmed from these researchers considering several species of the genus Chirostoma from the Arge group and probably also species from the Jordani group because they are morphologically similar and difficult to identify to the species. The standard phi *(Ø')* growth index, or growth evaluation index (Pauly and Munro 1984), calculated in this study was similar between males and females (Table 1). SL_∞ and k varied according to sex, SL_∞ was higher in females, and the growth coefficient k was lower in females, indicating that males grew slightly faster than females until reaching L_∞ (SL_∞); this was because of the inverse relationship between maximum length and growth rate (Gerking 1978). The acceleration and deceleration of *C. chapalae* growth throughout the study was possibly related to the reproductive cycle since it was observed that reproductive activity intensified in spring (Guzmán-Arroyo et al. 1995), and almost all stored energy was used for reproduction and not for growth (Sánchez-Merino et al. 2006). This was evidenced by the results of the condition factor (Kn), which showed an increase from November 2016 to January 2017, indicating general body robustness of the fish that decreased in February and March and transferred energy to the gonads followed by another increase in body condition from April that indicated maximum maturity and spawning. These variations could be related to the reproductive season of this species since this parameter is a quantitative indicator of the degree of welfare of the fish and refers to seasonal reproductive cycles and feeding (Lima-Junior et al. 2002). In fact, several studies have shown that there is a positive correlation between body fat accumulation and fish condition as either a close, direct or inverse relationship between gonadal development and seasonal variations in condition factor (Chellappa et al. 2003). Variations could also be related to factors such as sex, the size of individuals caught by selective gear, growth stages, time of year, geographical location, site and time of capture, stomach contents, sexual maturity stage, and food availability that affect the magnitude of Kn (Ricker 1975, Pauly and Munro 1984). Ibáñez et al. (2008) reported that the condition factor (Kn) of male and female *Chirostoma jordani* in Lake Meztitlán, Hidalgo, Mexico varied in some months and the highest Kn values were observed in December 2003, and in January and May 2004. In their study of *C. chapalae* from Lake Chapala caught with either gill nets or *atarray* tools, Elizondo-Garza and Fernández-Méndez (1996) estimated that Kn for males increased until May and decreased in June in specimens caught in gillnets, while in those caught with *atarray* tools Kn decreased at the beginning of the year. While females caught with gillnets showed a gradual decrease at the end of each year and then an increase at the beginning of the year and a decrease in April, which linked these results to the onset and peak of spawning and the emigration of mature females to the shores.

Several authors report that the fishery resources of Chirostoma species in natural lakes and artificial reservoirs in Mexico are overexploited (E > 0.5, Gulland 1971) (Arredondo-Vargas et al. 2013, Lyons et al. 1998); however, the *C. chapalae* population in Lake Chapala is apparently still at the optimum exploitation level (E < 05). This probably stems from the multi-species capture of Chirostoma species, which includes specimens of species of the Arge group (*Chirostoma jordani*, *C. arge*, *C. consocium*, *C. chapalae*, *C. labarcae*, and *C. contrerasi*) and the juvenile stages of specimens of species of the Jordani group (Gómez-Vanega 2018). This contrasts with what Arredondo-Vargas et al. (2013) reported for this lake since they indicated higher total mortality (Z = 3.26 year^{-1}) and fishing mortality (F = 2.13 year^{-1}) than that estimated in the present study. Natural mortality (M = 1.12 year^{-1}) was the exception. Estimations these researchers reported included specimens of various species of the Arge group, which could have affected the overall mortality calculations. These results were also likely related to variations in environmental conditions, the abundance of predators and existing competitors, and the strong impact of capture that directly influenced the presence and abundance of the six species of the Chirostoma complex in time and space (Sparre and Venema 1997). Likewise, habitat modifications, trophic alterations, and diseases (Torres-Orozco and Pérez-Hernández 2011) affected species differently. Finally, the results obtained corresponded to the first mortality estimates available for *C. chapalae* in Lake Chapala. The exploitation rates (E) estimated for the whole population (0.42 year^{-1}), for females (0.51 year^{-1}), and for males (0.45 year^{-1}) were relatively low. According to the Gulland (1971) criterion, which proposes that the value of E = 0.5 is the equilibrium point, the resources were not yet overexploited.

The catch sizes indicated that more than 50% of the *C. chapalae* in the lake were recruited to the fishery above the first catch size established by the Official Mexican Standard (NOM-032-SAG/PESC--2015: 61 mm SL, 75 mm TL; DOF 2015). This indicated sustainable, responsible use by Lake Chapala fishers using fishing gears within the standard, i.e., *nasa charalera* and gillnets with adequate mesh openings, and that the fish have the possibility of reaching reproductive size thus ensuring stocks of this resource in the future. The differences among the catch sizes of other species that coexist in the lake are related to biology, growth, age at sexual maturity, and climatic conditions and food availability (Narváez et al. 2013).

Knowledge of the biology, ecology, and the fishery of *C. chapalae* is almost completely lacking, so this research provides the first information on relevant aspects of the population dynamics of this species including its growth, condition, and mortality. Similarities in the morphology, physiology, ecology, and fisheries of sibling species from the Arge group of the genus Chirostoma (Aterinopsidae) in Lake Chapala, Mexico, makes the species-specific evaluation of *C. chapalae* resources necessary to contribute basic information on its biology and fishery for future studies and decision-making in the management and exploitation of one of the natural resources of the largest natural lakes in Mexico.

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References

Aguilar, J. F., Navarrete, N. S. (1996). Growth, condition and mortality of charal *Chirostoma humboldtianum* (Atheriniformes: Atherinidae) in Mexico. Revista de Biología Tropical, 44(3)/45(1), 573-578 (in Spanish).

Alcocer, J., Escobar, E. (1996). Limnological regionalization of Mexico. Lakes & Reservoirs: Research & Management, 2(1-2), 55-69.

Arredondo-Vargas, E., Osuna-Paredes, C., Meléndez-Galicia, C., Jesús-Avendaño, C., Hernández-Montaño, D. (2013). Lake Chapala, Michoacán and Jalisco, México. In: Inland Fisheries de México (Ed.) M. T. Gaspar-Dillanes, D. Hernández-Montaño, Instituto Nacional de Pesca. México, 35-52 (in Spanish).

Arriaga, H. V. M., Guzmán, A. M., Morelos, L. M. G. (1995). Food habits. In: Fishing in Lake Chapala: towards their rational management and exploitation. (Ed.) M. Guzmán-Arroyo. Universidad de Guadalajara – Comisión Nacional del Agua. Guadalajara, Jalisco, México, 119-141 (in Spanish).

Bagenal, T. B., Tesch F. W. (1978). Age and growth. In: Methods for assessment of fish production in fresh waters (Ed.) T.B. Bagenal. 3rd edition. Blackwell Scientific Publications, Oxford, England. 101-136.

Barbour, C. D. (1973). The systematics and evolution of the genus *Chirostoma*, Swainson (Pisces, Atherinidae). Tulane Studies in Zoology and Botany, 19(3), 97-141.

Beverton, R. J. H., Holt, S. J. (1959). A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. Ciba Foundation Symposium. The Lifespan of Animals, Colloquia on Ageing, 5, 142-180.

Braga, F. M. S. (1986). Study between condition factor and length/weight relation for some marine fishes. Revista Brasileira de Biologia, 46(2), 339-346 (in Portuguese).

CEA Jalisco. (2019). Lake Chapala. Available at https://www.ceajalisco.gob.mx/contenido/chapala/ (accessed January 30, 2019) (in Spanish).

Chellappa, S., Câmara, M. R., Chellappa, N. T., Beveridge, M. C. M., Huntingford, F. A. (2003). Reproductive ecology of a neotropical cichlid fish, *Cichla monoculus* (Osteichthyes: Cichlidae). Brazilian Journal of Biology, 63(1), 17-26.

CONAPESCA. (2018). Statistical Yearbook on Aquaculture and Fisheries. Comisión Nacional de Acuacultura y Pesca (CONAPESCA), SAGARPA. México. 300 (in Spanish).

Conover, D. O. (1984). Adaptive significance of temperature-dependent sex determination in a fish. The American Naturalist 123(3), 297-313

Contreras-Balderas, S., Ruíz-Campos, G., Schmitter-Soto, J. J., Díaz-Pardo, E., Contreras-McBeath, T., Medina-Soto, M., Zambrano-González, L., Varela-Romero, A., Mendoza-Alfaro, R., Ramírez-Martínez, C., Leija-Tristán, M. A., Almada-Villela, P., Hendrickson, D. A., Lyons, J. (2008). Freshwater fishes and water status in México: a country-wide appraisal. Aquatic Ecosystem Health and Management, 11(3), 246-256.

Csirke, J. (1980). Introduction to fish population dynamics. Fisheries Technical Document No 192. FAO, Roma, Italy. 82.

Curiel-Ballestero, A. (2014). Nature's goods and services. In: Jalisco in the contemporary world; contributions to a contemporary encyclopedia. (Ed.) H. R. Solís-Gadea, K. A. Planter-Pérez, Universidad de Guadalajara, Consejo Estatal de Ciencia y Tecnología. Vol. 4. Guadalajara, Jalisco, México. 297-304 (in Spanish).

de Anda, J., Shear, H. (2001). Nutrients and eutrophication in Lake Chapala. In: The Lerma-Chapala watershed. Evaluation and management. (Ed.) A.M. Hansen, M. van Afferden, Kluwer Academic Press, New York, 183-198.

DOF. (2015). Official Mexican Standard, NOM-032--SAG/PESC-2015. Responsible fishing in Lake Chapala, located in the states of Jalisco and Michoacán. Specifications for the use of fishery resources. Diario Oficial de la Federación. 1ª Sección. 19. Ciudad de México (in Spanish).

Echelle, A. A., Echelle, A. F. (1984). Evolutionary genetics of a species flock: Atherinid Fishes on the Mesa Central of México. In: Evolution of Fish Species Flocks. (Eds.) A. A. Echelle, I. Kornfield. University of Maine, Orono, 93-110.

Elizondo-Garza, R., Fernández-Méndez, J. I. (1996). Analysis of the catches of silverside *Chirostoma chapalae* with handline net and atarray in Lake Chapala, Michoacán, México. INP. SEMARNAP. Ciencia Pesquera, 13, 55-61 (in Spanish).

Filonov, A. E., Tereshchenk, I. E., Monzon, C. O. (2001). Hydrometerology of Lake Chapala. In: The Lerma-Chapala watershed. Evaluation and management. (Ed.) A. M. Hansen, M. van Afferden, Kluwer Academic Press New York, 151-182.

Froese, R. (2006). Cube law, condition factor and weight-length relationships: history, meta-analysis and recommendations. Journal of Applied Ichthyology, 22, 241-253.

Gallardo-Cabello, M. (1977). Contribution to the study of *Chirostoma chapalae* in Chapala Lake. Atherinidae. Mugiliformes. Bachelor's thesis in Biology. Facultad de Ciencias, UNAM. México. 87 (in Spanish).

Gayanilo, F. C., Sparre, P., Pauly, D. (1996). FAO-ICLARM stock assessment tools (FiSAT) user's guide. FAO Computerized Information Series (Fisheries) 8. FAO. Rome, Italy. 126 p.

Gerking, A. (1978). Ecology of freshwater fish production. Blackwell Scien. Pubs. London, UK. 480.

Gomez-Vanega, H. D. (2018). Silversides (charal) population structure and reproductive activity (Atherinopsidae: C*hirostoma*) in the Chapala Lake, México. Master's thesis in Biosystematics, Natural Resource Management and Agricultural, Centro Universitario de Ciencias Biológicas y Agropecuarias, Universidad de Guadalajara, Mexico. 98 (in Spanish).

Gulland, J. A. (1971). Manual of methods for the assessment of fish stocks. Editorial Acribia. Zaragoza, España. 164.

Gulland, J. A., Holt, S. J. (1959). Estimation of growth parameters for data at unequal time intervals. Journal of Conservation CIEM, 25, 47-49.

Guzmán-Arroyo, M. (1995). Fishing in Lake Chapala: towards its management and rational exploitation. Comisión Nacional del Agua – Universidad de Guadalajara, Guadalajara, México (in Spanish).

Guzmán-Arroyo, M., Merino-Nambo, E. (1995). Lake Chapala. In: Fishing in Lake Chapala: towards its management and rational exploitation. (Ed.) M. Guzmán-Arroyo, Comisión Nacional del Agua – Universidad de Guadalajara, Guadalajara, México, 29-48 (in Spanish).

Guzmán-Arroyo, M., Ortiz-Martínez, J. M. (1995). Spatial distribution. In: Fishing in Lake Chapala: towards its management and rational exploitation. (Ed.) M. Guzmán. Comisión Nacional del Agua – Universidad de Guadalajara, Guadalajara, México, 73-91 (in Spanish).

Guzmán-Arroyo, M., Galaviz, S., Morelos-López, M. G. (1995). Reproductive cycles. In: Fishing in Lake Chapala: towards its management and rational exploitation. (Ed.) M. Guzmán-Arroyo. Comisión Nacional del Agua – Universidad de Guadalajara, Guadalajara, México, 93-117 (in Spanish).

Guzmán-Arroyo, M., Peniche-Camps, S., Valdés-Zepeda, A. (2003). The Lerma River and Lake Chapala basin. In: Chapala a programmed crisis. (Ed.) M. Guzmán-Arroyo. Chamber of Deputies, Honorable Congress of the Union of the State of Jalisco. Guadalajara, México. 12-58 (in Spanish).

Ibáñez, A. L., García, J. L. C., Torres, R. O. (2008). Reproductive aspects of "charal" *Menidia jordani* (Woolman) from Lake Meztitlán, Hidalgo. Hidro-biológica, 18(1), 1-9 (in Spanish).

IUCN, (2021). The IUCN Red List of Threatened Species. Version 2021-3. https://www.iucnredlist.org. Accessed on 30 January 2021.

Jiménez-Badillo M.L., Gracia A. G. (1995). Assessment of the multispecies charales fishery (*Chirostoma* spp., Pisces, Atherinidae) from Lake Pátzcuaro, Michoacán, México. Anales del Instituto de Biología. Serie Zoología, 66(2), 205-231 (in Spanish).

Lima-Junior, S. E., Cardone, I. B., Goitein, R. (2002). Determination of a method for calculation of allometric condition factor of fish. Act Scientiarum, 24(2), 397-400.

Lindeman, K. C. (1989). Coastal construction, larval settlement, and early juvenile habitat use in grunts, snappers and other coastal fishes of southeast Florida. Bulletin of Marine Science, 44(2), 1068-1089.

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.

Martínez-Palacios, C. A., Ríos-Durán, M. G., Campos-Mendoza, A., Toledo-Cuevas, M., Ross, L. G. (2002). Advances in the culture of Patzcuaro whitefish *Chirostoma estor estor*. In: Advances in Aquaculture Nutrition VI. Proceedings of the VI International Symposium. (Ed.) L. E. Cruz-Suarez, M. Ricque-Marie, M. Tapia-Salazar, M. G., Gaxiola-Cortes, N. Simoes, Cancún, Quintana Roo, México, 336-351.

Martínez Palacios, C. A., Racotta, I. S., Ríos-Durán, M. G., Palacios, E., Toledo-Cuevas, M., Ross, L. G. (2006). Advances in applied research for the culture of Mexican silversides (*Chirostoma*, Atherinopsidae). Biocell, 30(1), 137-148.

Miller, R. R., Minckley, W. L., Norris, S. M. (2005). Freshwater Fishes of Mexico. University of Chicago Press, Chicago, IL.

Miller, R. R., Minckley, W. L., Norris, S. M. (2009). Peces dulceacuícolas de México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. Sociedad Ictiológica Mexicana, A.C. El Colegio de la Frontera Sur. Consejo de los peces del Desierto, México – Estados Unidos. – xxiii, 559.

Moncayo-Estrada, R., Lind, O. T., Escalera-Gallardo, C. (2010). Trophic partitioning of sympatric zooplanktivorous silverside in a tropical shallow lake: fish morphometry and diet composition. Copeia, 2010(3), 431-436.

Moncayo-Estrada, R., Lind, O. T., 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.

Moncayo-Estrada, R., Escalera-Gallardo, C., Lind, O. T. (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, 815-824.

Morelos-López, M. G., Guzmán-Arroyo, M. (1995). Ichthyofauna of the lake. In: Fishing in Lake Chapala: towards its management and rational exploitation. (Ed.) M. Guzmán Arroyo. Comisión Nacional del Agua – Universidad de Guadalajara, Guadalajara, México, 49-71 (in Spanish).

Narváez, B. J. C., De la Hoz, M. J., Racedo, J. B., Bolívar, F., Rivera, R. M., Álvarez, T., Mora, A. R., Bonilla, O.B., Riascos, C.C. (2013). Minimum catch sizes for sustainable harvesting of the main commercial fish species in Colombia. Universidad del Magdalena. Colombia. 37 (in Spanish).

Nikolsky G. V. (1963). The ecology of fishes. Academic Press.

Pauly, D. (1979). Theory and management of tropical multispecies stocks: a review, with emphasis on the Southeast Asian demersal fisheries. ICLARM Studies and Review, 1, 1-35.

Pauly, D., Munro, J. L. (1984). Once more on the comparison of growth in fish and invertebrates. Fishbyte, 2(1), 1-21.

Ricker, W. E. (1975). Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada. Bulletin, 191, 1-382.

Rodríguez-Jorquera, I. A., Siroski, P., Espejo, W., Nimptsch, J., Choueri, P. G., Choueri, R. B., Moraga, C., Mora, M., Toor, G. S. (2017). Latin American protected areas: Protected from chemical pollution? Integrated Environmental Assessment and Management, 13(2), 360-370.

Rojas-Carrillo P., Fernández-Méndez J. I. (2006). Fishing in inland waters. In: Fisheries, aquaculture and research in Mexico. (Ed.) P. Guzmán-Amaya, D.F. Fuentes-Castellanos. Centre of Studies for Sustainable Rural Development and Food Sovereignty and Food Sovereignty. Chamber of Deputies. Ciudad de México. 5(4), 49-67 (in Spanish).

Sánchez-Merino, R., Díaz-Zaragoza, M., Navarrete-Salgado, N. A., García-Martínez, M. L., Ayala-Nińo, F., Flores-Aguilar, M. D. (2006). Growth, mortality and survival rate of silverside fish *Chirostoma humboldtianum* (Atherinopsidae) from the San Miguel Arco Reservoir. Revista Chapingo Serie Ciencias Forestales y del Ambiente, 12(2), 151-154 (in Spanish).

Sánchez-Torres, J. D., Nuño-Sánchez, S. A., Martínez-Alvarado, J. C., Ruiz-Cruz, R. (2018). Lake Chapala Water Quality Data Analysis Report. Department of Mathematics and Physics. ITESO, Jalisco, México (in Spanish).

Slack-Smith, R. J. (2001). Fishing with traps and pots. FAO Training Series, No. 26, FAO, Rome, Italy.

Sparre, P., Venema, S. C. (1997). Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fisheries Technical Paper, No. 306. FAO, Rome, Italy.

Taylor, C. C. (1958). Cod growth and temperature. Journal du Conseil International Pour l´Exploration de la Mer, 23(3), 366-370.

Taylor, C. C. (1960). Temperature, growth and mortality, of the Pacific cockle. Journal du Conseil International Pour l´Exploration de la Mer, 26(1), 117-124.

Torres-Orozco, R., Pérez-Hernández, M. A. (2011). Mexico's fish: a richness under threat. Revista Digital Universitaria, 12(1), 1-15 (in Spanish).

Vazzoler, A. E. A. M. (1996). Reproductive biology of teleost fish: theory and practice. EDUEM, Maringa, Sao Paulo, Brasil.

Von Bertalanffy, L. (1938). A quantitative theory of organic growth. (Inquiries on growth laws. II). Human Biology, 10(2), 181-213.

Wetherall, J. A., Polovina, J. J., Ralston, S. (1987). Estimating growth and mortality in steady-state fish stocks from length-frequency data. ICLARM Conference Proceedings, 13, 53-74.

Zar, J. (2009). Biostatistical analysis. Prentice Hall, New Jersey, USA.