

Reproduction of *Mugil cephalus* (Percoidei: Mugilidae) off the Central Mexican Pacific Coast

Elaine Espino-Barr^{1*}, Manuel Gallardo-Cabello², Marcos Puente-Gómez¹ and Arturo Garcia-Boa¹

¹Instituto Nacional de Pesca, Playa Ventanas s/n, Manzanillo, Colima, México

²Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, México

Abstract

Reproduction of *Mugil cephalus* of the Pacific coast of Mexico was studied. Fish were captured with gill nets and cast nets; they are a common low priced product for local consumption. The study of the reproduction period and ages of first maturity helps manage the fishery. Fish were obtained from local commercial fishery from August to December 2007, January to March 2008 and November 2012 to October 2013. Size and weight, sex and gonad maturity were registered. The male:female ratio was 0.88:1. Mature organisms occurred all year round. Sexual maturation (L_{50}) of males and females was observed at a mean size of 34.0 cm in males (4.64 years of age) and 35.0 cm in females (4.98 years of age). First maturity length (L_{25}) was both 30.0 cm in males and females corresponding to 3.4 years of age in both cases. The allometric relationship with the hepatosomatic index was $LW=4.00 \cdot 10^{-3} \cdot TL^{2.771}$ ($r^2=0.849$). Condition factor indexes of Clark and Safran EW showed a maximum increment during June, August and December; Fulton and Safran TW in July and September to November. The gonadosomatic index showed its highest values from November to January. The hepatosomatic index reached its maximum values in June, July and August. The gastric repletion index reached its highest values in June, February and October. The mean oocytes diameter was 0.38 mm (range 0.22 to 0.52 mm, standard deviation=0.13). Fecundity ranged from 1'422,076 to 1'747,736 oocytes in females between ages 3 and 12 years old, and mean relative fecundity was 2,830 oocytes·g⁻¹ (1,500 to 2,900 oocytes·g⁻¹). This study is the base line for the fishery management of *M. cephalus* in Central Mexican Pacific, where the main regulations need information on the first maturity size and reproductive season.

Keywords: Fecundity; Maturity period; Fish reproduction; Gonadosomatic index; Hepatosomatic index; Gastric repletion index; Condition factor

Introduction

The striped mullet *Mugil cephalus* Linnaeus 1758 (Figure 1) has a worldwide distribution between 42°N and 42°S [1]. Through the biogeographic areas and provinces of the American continent, the only exceptions are the cold temperatures of the Northeast Pacific in the Pacific Province and the Magellanic Province in South America [2]. In the Western Atlantic it distributes from Nova Scotia to Argentina including the Gulf of Mexico [3]. In the Eastern Pacific it distributes from California to Chile, including the Gulf of California and Galapagos Islands [4].

New research made by Whitfield et al. establishes that *M. cephalus* is a cosmopolite species that flourishes in a high variety of habitats and that can be considered as a eurytopic species complex, and could be used as a biological marker in the health levels of different ecosystems where it inhabits [5].

This species is important for the meat consumption and the “roe” (female mature gonads), which reaches a higher price than the meat: the roe is \$300.00 Mexican pesos per kilogram (\$18.00 US dollars) and the meat \$30.00 Mexican pesos (\$1.80 US dollars) per kilogram.

M. cephalus ranks in 22nd place in Mexican fisheries, with a capture of 12 280 [6]. This species has been studied in many parts of the world where well established fisheries are located. In the case of Mexico, analysis has also been carried out on this fishery and biological aspects [7-20]. However, most of the studies in Mexico have been carried out in the Tamiahua lagoon, Tamaulipas, on the Atlantic Ocean, or in Mazatlán, Sinaloa and Nayarit on the northern Mexican Pacific Ocean.

In the coast of Jalisco and Colima, *M. cephalus* does not reach a high catch volume as in these other places, but it is part of a multispecific

fishery and important to know the health status of their populations. Traditionally *Mugil curema* is fished in a higher amount in the coasts of Jalisco and Colima, than *M. cephalus*. In 2014, *M. curema* was fished up to 626 tons (79% of the total Mugilidae species), and 167 tons of *M. cephalus* (21% of the total Mugilidae species) [6]. Therefore *M. curema* has been analyzed and some studies of its population dynamics were done [21-26].

The objectives of the present study were to analyze monthly frequency of the gonadic maturity stages and massive spawning

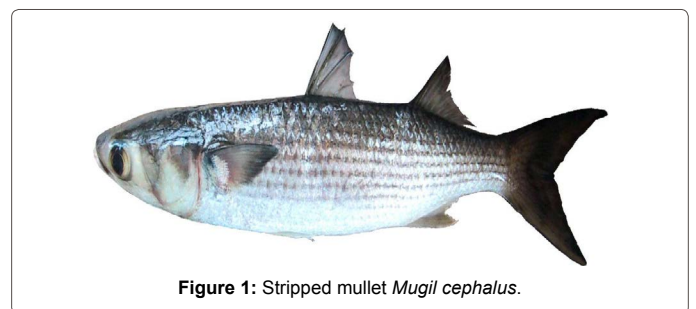


Figure 1: Striped mullet *Mugil cephalus*.

***Corresponding author:** Elaine Espino-Barr, Instituto Nacional de Pesca, Playa Ventanas s/n, Manzanillo, Colima, México, Tel: (314)1067756, 52(314)3323750; Fax: 52(314)3323751; E-mail: elespino@gmail.com

Received April 15, 2016; **Accepted** September 08, 2016; **Published** October 18, 2016

Citation: Espino-Barr E, Gallardo-Cabello M, Puente-Gómez M, Garcia-Boa A (2016) Reproduction of *Mugil cephalus* (Percoidei: Mugilidae) off the Central Mexican Pacific Coast. Fish Aquac J 7: 180. doi:10.4172/2150-3508.1000180

Copyright: © 2016 Espino-Barr E, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

period; monthly values of the gonadosomatic and hepatosomatic index; monthly values of the gastric repletion index; monthly values of the condition factor of Fulton, Clark and Safran; values of total and relative fecundity; and to compare our results to those reported by other authors [27-29].

These studies will give a solid background for closed seasons and gill net mesh sizes, based on the minimum reproductive size. These fishing measures will allow the species to reproduce at least once, protecting the fishery from overexploitation.

Materials and Methods

From August to December 2007, January to March 2008 and November 2012 to October 2013, *M. cephalus* samples were monthly collected in the Cuyutlan Lagoon, Colima, Mexico (103°57'-104°19' W and 18°57'-19°50' N) and in Cruz de Loreto Lagoon, Jalisco, Mexico (105°27'-105°33' W and 19°58'-20°05' N) (Figure 2). The fishing gears were gill-nets of 2.0, 2.5, 3, 3.5 and 4 inches mesh size (5.08, 6.35, 7.62, 8.89 and 10.16 cm). Total length was measured to the nearest millimeter (TL, cm) from the snout tip to the caudal fin extreme in 262 organisms (fishermen deliver this species intact); the total (TW, g) and eviscerated (EW, g) weight of 784 specimens (weighed to the nearest 0.1 g) were measured.

The function $W=a \cdot L^b$ was used to obtain weight-length relationship and sex was recorded macroscopically for each specimen. Sexual maturation was determined *in visu* on fresh organisms taken to the laboratory the same day they were caught. Sokolov and Wong, Holden and Raitt, Aboussouan and Lahaye and Espino-Barr suggest a scale to determine sexual maturity and describe the stages as follows [30-33]:

- Phase I: Sexually immature organisms, in which sex cannot be distinguished, the gonads are very fine filaments.
- Phase II: Organisms have not yet matured sexually, the testis start to develop and are light colored and ovaries are pale pink, and oocytes cannot be observed.
- Phase III: Sexual maturity begins; sexual glands can be perfectly identifiable. Oocytes are beginning to form and are opaque, the color of the ovaries start to turn dark pink, testis also show darker and opaque color.
- Phase IV: Mature, sexual glands are well developed, ovaries are rose-orange, oocytes are big and transparent, and testes are whitish.
- Phase V: This stage corresponds to the spawning, both, ovules and sperm that are expelled if the visceral cavity is pressed, gonads show and intense blood supply and both ovaries and testes show brighter colors.
- Phase VI: Corresponds to the post-spawning, sexual products have been expelled, both ovaries and testes are empty, gonads coloring tend towards a dark pink.

Sparre and Venema suggest that the first spawn length is calculated as the 50% of the accumulative frequency (L_{50}) of phases IV and V of the sexual maturity scale mentioned above, considering that the lowest spawning length (L_{25}) is also registered, to compare with data reported in other studies [34,35]. This kind of analysis is carried out for both males and females and both (L_{25}) as (L_{50}) are useful because deliver information on the stages close to the reproduction. Gaertner and Laloe and Sparre and Venema represent this function by the equation [34,36]:

$$H_p = 1/[1 + e^{a+b \cdot TL}],$$

where: H_p = the percentage of mature organisms (males or females) and a and b are constants.

Transforming this equation logarithmically, we obtain:

$\ln 1/(H_p - 1) = a + b \cdot TL$, and the length at which 50% of the population is sexually mature (L_{50}) corresponds to: $L_{50} = a/b$.

To include L_{50} , the original equation is modified:

$$Y = 1/[1 + a \cdot (1 - TL/L_{50})]$$

The minimum TL of first spawning (L_{25}) was also recorded to be compared with other authors' findings.

The formula mentioned by Rodríguez-Gutiérrez to calculate the gonadosomatic index (GSI) for males and females of *M. cephalus* [35], considers the gonad weight (GW) in relation to the fish total weight,

i.e., $GSI = 100 \cdot GW/TW$ (TW = total weight).

To measure physical fitness of fish, we obtained the condition factor

$$K = (EW \cdot TL^{-3}) \cdot 100,$$

$$K = (TW \cdot TL^{-3}) \cdot 100 \text{ and}$$

$$a = TW \cdot TL^{-b} \text{ and}$$

$$a = EW \cdot TL^{-b} [27-29].$$

The hepatosomatic index (HSI), expressed as the percentage of

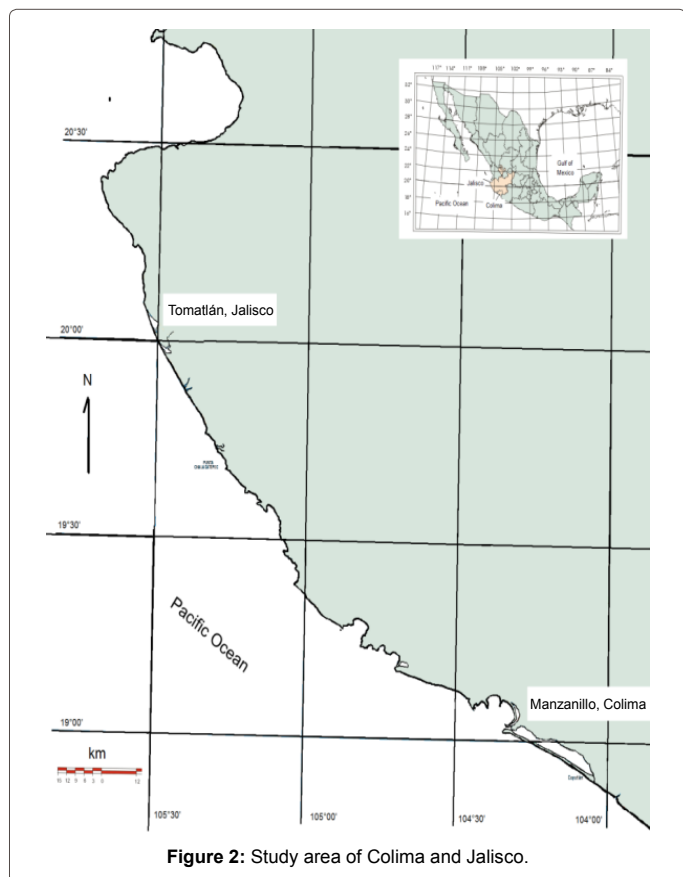


Figure 2: Study area of Colima and Jalisco.

liver weight (LW) with respect to the total weight was calculated as:

$$HSI=100 \cdot LW/TW \text{ [35].}$$

The stomach repletion index is the relation between the stomach weight and the body weight, calculated individually and averaged monthly.

The gravimetric method was used to calculate total fecundity (F) and relative fecundity (Fr) using the weight of 45 females in phase V of gonadic maturity. To estimate F, two subsamples of 0.1 g were obtained of each individual and put in modified Gilson fluid for preservation [37]. All oocytes were counted with the help of a stereoscopic microscope and measured with an ocular micrometer.

The following formula was used to determine fecundity:

$$F=n \cdot G_i/g_s,$$

where n =number of oocytes in the subsample; G_i =weight of the gonad (g) and g_s =weight of the subsample (g) [31].

The relationship between fecundity and total length and weight was calculated with the formula

$$F=a \cdot x^b,$$

where x =individual weight or length, a =intercept or initial number of oocytes, b =slope or oocyte number changing rate.

The data obtained by Espino-Barr et al. in the study of otoliths, were used to obtain –for each age- the relations between TL, TW, LW, testis weight (TeW), ovary weight (GW), and fecundity [19].

Results

M. cephalus sex cannot be differentiated by their body morphology, so organisms have to be opened and eviscerated; 262 individuals were sexed. The use of gill nets of different size (2.0-4.0 μ m) in commercial fishery allowed catching individuals of various age groups.

Once organisms begin their gonadal maturity, sex identification is performed quite easily. Ovaries are elongated and during the season close to spawning, oocytes are easily observed, with a bright yellow pink coloration.

The relationship from each age group to the values of the total length (TL, cm), total weight (TW, g), eviscerated weight (EW, g), liver weight (LW, g), gonad weight (TeW, g and GW, g), and fecundity (number of oocytes) are shown in Table 1.

Testes are cream colored long triangular tape type and smaller than ovaries.

Oocyte diameters were 0.38 mm (from 0.22 to 0.52 mm \pm 0.12 mm standard deviation: SD). The fecundity values oscillated from 1'422,076 to 1'747,736 oocytes in females from 3 to 12 years of age, length from 28.5 cm to 48.8 cm, and total weight 239 g to 1,165 g (Table 1). Relative fecundity showed average values of

$$Fr=2,830 \text{ oocytes} \cdot g^{-1} \text{ (ranging from 1,500 to 2,900 oocytes} \cdot g^{-1}\text{).}$$

The sample size was of 262 organisms of *M. cephalus*, of which 123 were female (46.95%), 109 male (41.60%), and 30 undetermined (11.45%). The male: female proportion was 0.88: 1.0.

According to the values obtained of the monthly frequencies for the gonadal maturity scale, it was observed that immature male organisms corresponding to Phase II prevailed from March to August in 100% with high values also in September and October. Immature females were present with more than 50% in February, May, August and December (Figures 3a and 3b). Phase III: Maturing, females were not present and males showed up during January and November, while phase IV, mature, was observed in July, September and October for females and in January for males. Phase V or spawning stage was observed in females in November, January and February. Males were in phase V in September and from November to January. Phase VI, post-spawning, females were observed during all year round, with high values in March, April, June, July, September and October, while males were present in February, October, November and December (Figures 3a and 3b).

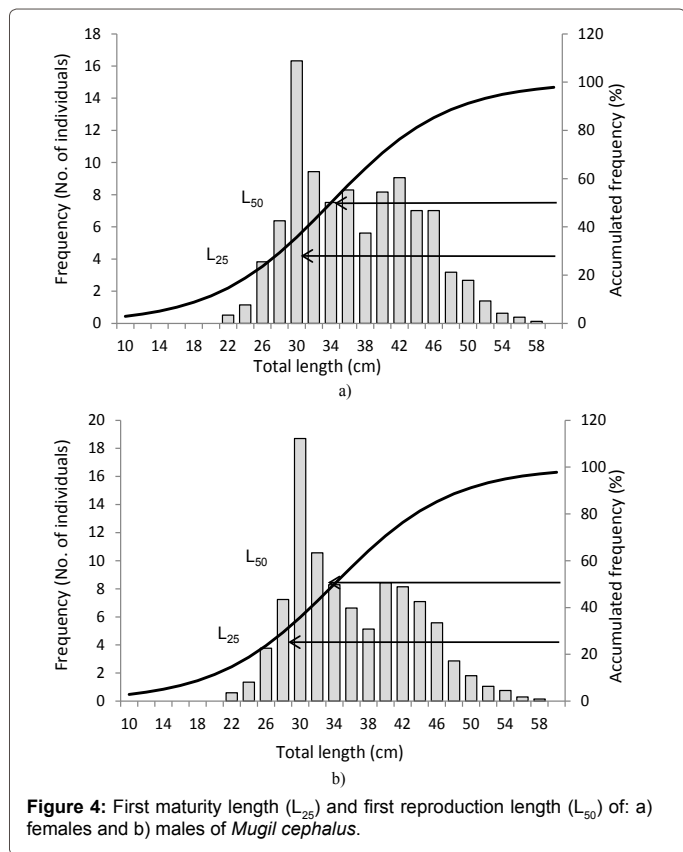
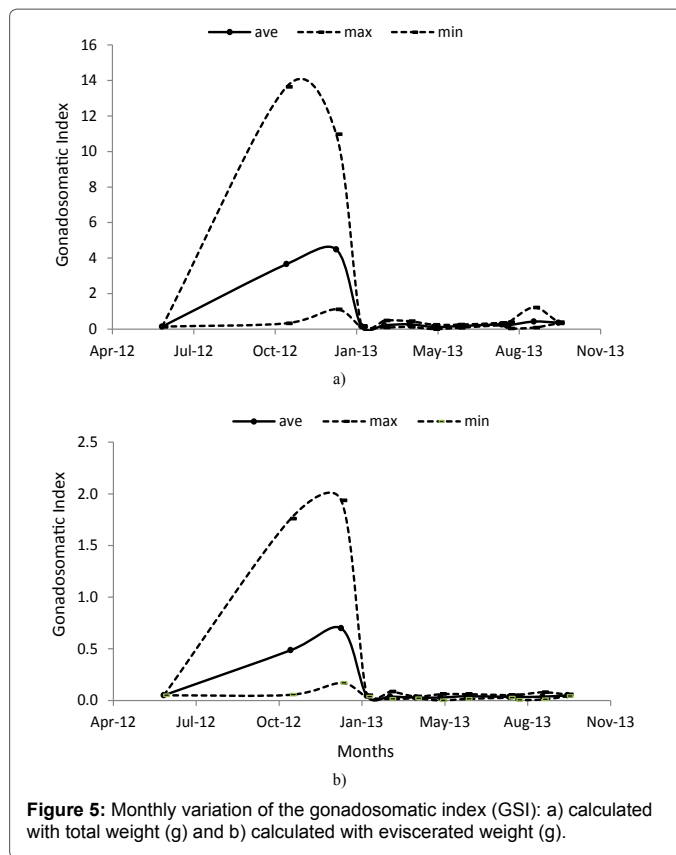
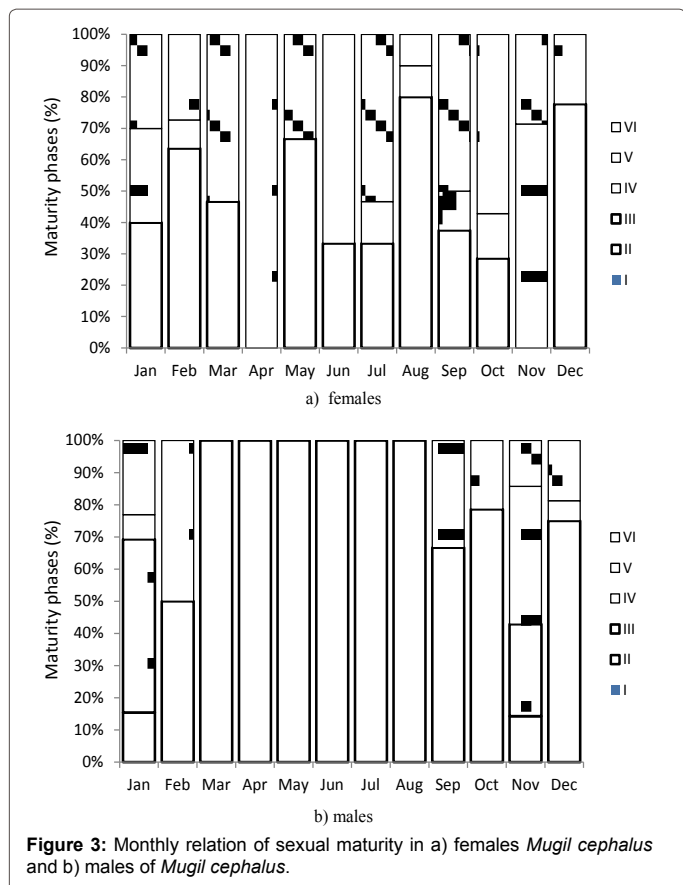
Length at first maturity was L_{25} =30.0 cm in females (Figure 4a) and in males (Figure 4b), corresponding to 3.4 years of age. First reproduction length was L_{50} =35.0 cm in females (Figure 4a) and L_{50} =34.0 cm in males (Figure 4b), which correspond to 4.98 and 4.64 years of age, respectively.

The gonadosomatic index (GSI) showed the highest values in November and January for total length and total and eviscerated weight (Figures 5a and 5b), followed by a very light increase of GSI values during September and October only observed for total length and total weight. GSI values were very low the rest of the year.

We obtained the following allometric relationships of the hepatosomatic index (HSI) $LW=4.00 \cdot 10^{-3} \cdot TL^{2.771}$ ($r^2=0.849$). The index b shows that, in terms of length, the liver weight is lower than a cubic proportion, which results in a negative allometric growth of the fish

Age	TL (cm)	TW (g)	EW (g)	LW (g)	TeW (g)	GW (g)	F (eggs)
0	15.62	40.000	33.000	0.767	-	-	-
1	20.43	89.000	74.000	1.604	-	-	-
2	24.71	156.000	130.000	2.706	-	-	-
3	28.53	239.000	198.000	4.018	1.440	2.379	1,422,076
4	31.94	333.000	277.000	5.481	2.966	4.216	1,485,136
5	34.98	436.000	362.000	7.037	5.308	6.684	1,537,943
6	37.69	544.000	451.000	8.640	8.557	9.756	1,582,684
7	40.11	653.000	542.000	10.253	12.743	13.374	1,620,990
8	42.26	762.000	633.000	11.836	17.799	17.426	1,653,846
9	44.18	869.000	722.000	13.374	23.653	21.827	1,682,328
10	45.90	973.000	808.000	14.855	30.202	26.489	1,707,202
11	47.42	1,072.000	890.000	16.248	37.203	31.245	1,728,711
12	48.79	1,165.000	967.000	17.571	44.642	36.097	1,747,736

Table 1: Length (TL, cm), total weight (TW, g), eviscerated weight (EW, g), liver (LW, g), testis weight (TeW, g), ovary weight (GW, g) and fecundity (number of oocytes) for each age group (years).



and a decrease of its fatty reserves as it ages. HSI variations are shown in Figures 6a and 6b; maximum values are observed in May, June and July and lower values in February and March.

The differences in the stomach repletion index (Figures 7a and 7b) showed higher values during June, February and October; lower values are observed in December, January and September.

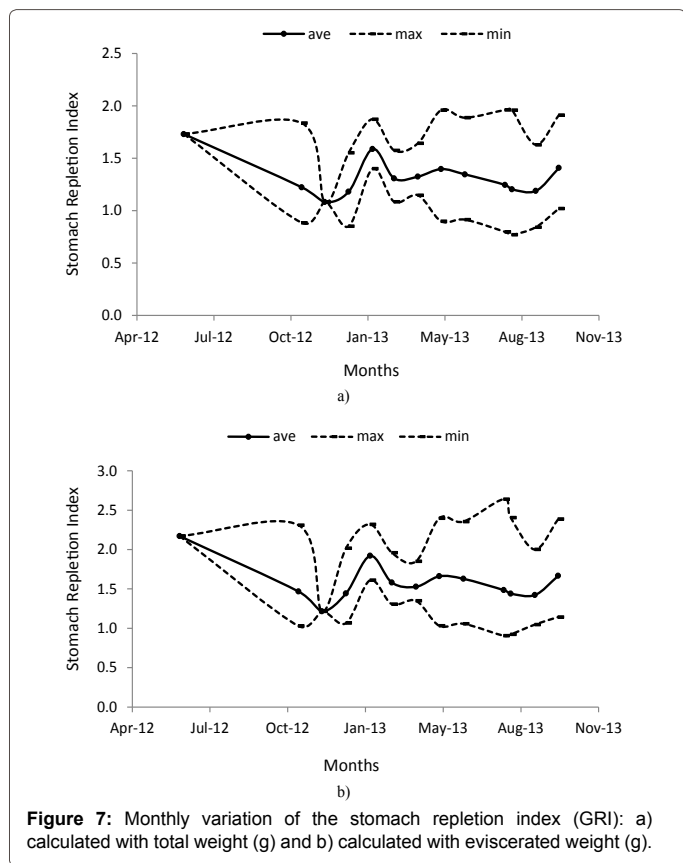
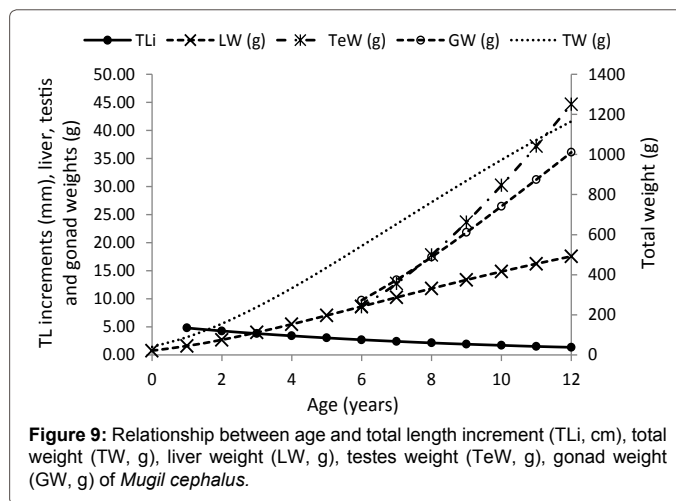
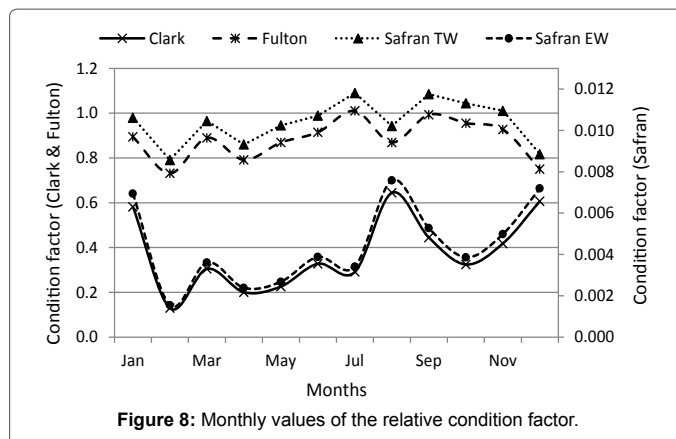
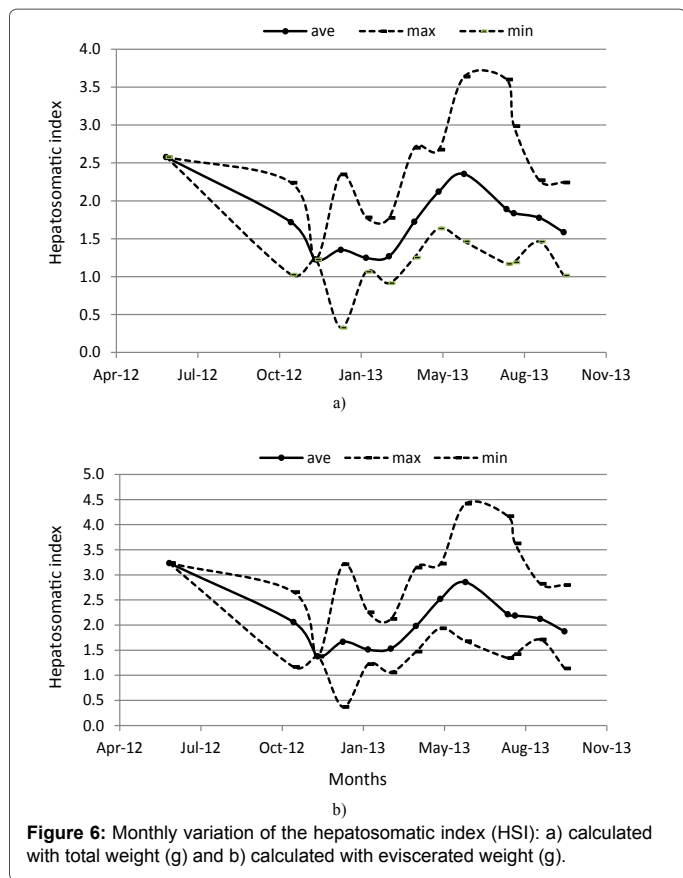
Figure 8 shows data of the condition factor; the highest values are obtained in January, August and December for Clark index and Safran EW. For Fulton index and Safran TW the highest values correspond to July, September, October and November.

Discussion

The highest length growth rates of *M. cephalus* calculated by Espino-Barr et al. are in groups zero and three years of age, a second period corresponds between ages 4 and 7 years, and a third period between ages 8 and 12 years, which show the lowest length growth rate [19]. As length growth rate starts to decrease, total weight, gonad weight and fatty reserve index start to rise. In this way, two main seasons were registered in the life cycle of *M. cephalus*: first, from ages zero and three when most of the energy obtained through food is used to increase its length (reducing depredation and interspecific competence), and second from ages four to twelve, when this energy is oriented to form the sexual products and fatty reserves (Figure 9) [33,38,39].

Sexual proportion was 0.88:1 male:female, values slightly higher of 1:1.1 male:female were found for *M. cephalus* in Tamiahua lagoon in the Atlantic sea [40].

During all year round *M. cephalus* specimens were observed in post spawning phase (Figure 3), which indicates that during every months



mature organisms are present and that the reproduction carries out during every month of the year. However, most of the organisms in spawning phase occur during November, December and January. In the case of *M. cephalus* of Tamiahua, Veracruz, spawning occurs during autumn and winter, coinciding with the northern winds [40].

The highest first reproduction size of *M. cephalus* (L_{50}) was 42.52 cm in males and females which corresponds to an age of three years, in the Gulf of México (Table 2), followed by Briones-Avila who obtained values of 38.00 cm in males and females of specimens from Nayarit and Sinaloa in the Mexican Pacific [7,41,42]. Render et al. found sizes of 36.95 cm in organisms of Louisiana in USA [43]. Hubbs reported lengths of 33.00 cm in males and 35.00 cm in females with two years of age in Florida, USA [44]. Organisms of smaller lengths have been reported by Arnold [45,46], Jacot et al. in the coasts of Florida, and by Oren in Texas and Florida, USA [47]. In the present study males reached first reproduction length at 34.0 cm (4.64 years old) and females at 35.0 cm of total length and 4.98 years of age

The gonadosomatic index (GSI) reached the highest values in November and January in this study (Figures 5a and 5b). Similar spawning seasons to the present study (November to February), were found in Tamiahua lagoon Veracruz, Mexico [40], in North Carolina and to lower Florida [48], in Hawaii [49], in southwestern Taiwan [50], west coast of Taiwan [51], northeastern coasts of Taiwan [52], south west of Bay of Bengal [53]; in all these areas the massive spawning period of *M. cephalus* is from the end of autumn and during winter.

Area	Males		Females		Author
	TL (cm)	Age (yr)	TL (cm)	Age (yr)	
Florida (E), USA	30.36	2	30.36	2	Jacot [45]
Florida, USA	33.00	2	356.00	2	Hubbs [44]
Gulf of Mexico	24.00	-	25.80	-	Arnold and Thompson [46]
Gulf of Mexico	42.52	3	42.52	3	Márquez-Millán [7]
Texas, USA	20.00-35.50		25.00-35.00		Oren [47]
Florida (W), USA	23.00-29.00	3	24.00-31.00	3	Oren [47]
Florida (E), USA	23.60	2	25.00	3	Oren [47]
Louisiana, USA	36.95		36.95		Render [43]
Gulf of Mexico	28.00	3	29.90	3	Ibáñez-Aguirre and Gallardo-Cabello [40]
Nayarit, Mexico	38.00	-	38.00	-	Briones-Ávila [41]
Sinaloa, Mexico	38.00	-	38.00	-	Briones-Ávila [42]
Mexican Central Pacific	30.00-34.00	3.4-4.64	30.00-35.00	3.4-4.98	This study

Table 2: First maturity (L_{25}) and reproduction (L_{50}) length of *Mugil cephalus* in different places.

Country	Locality	Period	J	F	M	A	M	J	J	A	S	O	N	D	Author
Australia	east coast	March-July	-	-	x	x	x	x	x	-	-	-	-	-	Kailola [58]
Australia	west coast	March-September	-	-	x	x	x	x	x	x	x	-	-	-	Kailola [58]
South Africa	Natal estuaries	May-August	-	-	-	-	x	x	x	x	-	-	-	-	Marais [54]
Russia	Primorye	May-September	-	-	-	-	x	x	x	x	x	-	-	-	Novikov [55]
France	France	July-November	-	-	-	-	-	-	x	x	x	x	x	-	Keith and Allardi [56]
Spain	Minorca (Balearic Archipelago)	August-November	-	-	-	-	-	-	-	x	x	x	x	-	Cardona [57]
India	southwest Bay of Bengal	October-December	-	-	-	-	-	-	-	-	-	x	x	x	Jeyaseelan [53]
Taiwan	northeastern coasts	December-January	x	-	-	-	-	-	-	-	-	-	-	x	Hsu [52]
Taiwan	West coast	december	-	-	-	-	-	-	-	-	-	-	-	x	Shung [51]
Taiwan	southwestern Taiwan	October-February	x	x	-	-	-	-	-	-	-	x	x	x	Chang [57]
Hawaii	Hawaii	December-February	x	x	-	-	-	-	-	-	-	-	-	x	Honebrink [49]
USA	North Carolina to lower Florida	October-February	x	x	-	-	-	-	-	-	-	x	x	x	Scotton [48]
USA	Delaware Bay	June-August			-	-	-	x	x	x	-	-	-	-	Scotton [48]
Mexico	Tamiahua Lagoon, Veracruz	December-February	x	x	-	-	-	-	-	-	-	-	x	x	Ibáñez-Aguirre and Gallardo-Cabello [40]
Mexico	Central Pacific (Jalisco and Colima)	-	x	-	-	-	-	-	-	-	-	-	x	x	Present study

Table 3: Spawning seasons of *Mugil cephalus* in different places.

However in other parts of the world, spawning of *M. cephalus* occurs mainly during summer, as is the case of Delaware Bay [48], Natal estuaries of South Africa [54] and Primorye, Russia [55]. In other areas the maximum reproduction of *M. cephalus* takes place during summer and early winter, as occurs in France [56] and the Balear Island of Menorca, Spain [57]. Also spawning of *M. cephalus* can occur during spring and summer as is the case of the east and west coast of Australia [58] (Table 3).

The hepatosomatic index obtained in this study was

$$b=2.771 (r^2=0.849),$$

which indicates a negative allometric growth; since fish decrease their fatty reserves as they grow older. In the case of *M. cephalus* in the Tamiahua lagoon, Veracruz, the relationship obtained for the hepatosomatic index showed an isometric growth $b=3.0$, which shows that the increments of the liver weight are directly proportional to the cubic length [40].

Monthly values of hepatosomatic index (Figures 6a and 6b) showed

that the liver accelerates its activity of reserving fatty acids during the periods before spawning; therefore, their weight increases considerably. The highest activity of fatty acid reserves is in June, July and August and starts to decrease in February and March after the spawning period of November, December and January. A similar phenomenon was observed in Tamiahua, where the fatty acids accumulation occurred in previous spawning periods [40]. However the largest accumulation of fatty acids was in the abdominal cavity instead of the liver. Ibáñez and Gallardo-Cabello reported this same observation in *M. cephalus* in Tamiahua, where the accumulation of glycogen is so intense in the periods previous spawning, that the stored reserve of hepatic acids is insufficient, which shows a sub estimated hepatosomatic index of the fatty acids reserve in the animal's body [40].

Variations in the stomach repletion index (Figures 7a and 7b) showed higher values during June, February and October, which are the months previous to spawning and higher accumulation of fatty acids reserve in the liver. Once the spawning has occurred, in the months of November, December and January, values of the gastric repletion values decline significantly.

Figure 8 shows the values of the condition factor; the highest values are obtained in January, August and December for the Clark index and Safran with eviscerated weight values (EW). For the Fulton index and Safran with total weight (TW) the highest values correspond to July, September, October and November. In all cases the highest were in the months previous to spawning or at its beginning. Similar values were obtained in Tamiahua where the highest value of the condition factor increments before the spawning period and decreases at its end; in May is when the higher recovery of the condition factor occurs [40].

Table 4 shows the fecundity values of *M. cephalus* in different countries; the highest values correspond to the Black Sea, where it can reach values over 7 million of oocytes [47]. Also Berg reports in the same area 7 million of oocytes in organisms of 52.00 cm of total length and 13 years of age [47]. In the Hawaiian Islands, Keith et al. found a maximum fecundity of 7 million of eggs; in Mauritania [59], Brulhet found a maximum of 6 million, and Popescu of 5 million in organisms from the Danubian delta [47]. Grant and Spain reported 4 million 800 thousand in Australia [60]. Values of fecundity of 3 million 790 thousand eggs were reported in SW Korea by Yang and Kim, and of 3 million in Taiwan by Tung and Hsu [52,61,62]. Solís found a maximum value of fecundity for *M. cephalus* in Tamaulipas, Mexico in the Atlantic Ocean of 2 million 919 thousand oocytes in females of 48.00 to 56.00 cm of total length [63]. In Australia, Thomson and Kesteven reported 2'781,000 and Tosh 2 million and a half in females of *M. cephalus* [47,64,65]. In Mauritania and Senegal, Landret found a value of 2'322,400 oocytes [47]. In our study values of 1'582,684 to 1'747,736 oocytes in females of the coast of the Central Mexican Pacific (Jalisco and Colima) were found in organisms of 37.70 to 48.80 cm of total length and 6 to 12 years of age. The lowest values were reported by Ibáñez and Gallardo-Cabello of 898,512 oocytes in females of 38.00 cm total length and 6 years of age, from the Tamiahua lagoon, Veracruz, Mexico, although these authors mention to have found fecundity values of 1'483,056 oocytes in females older than 6 years of age [40]. At last, Shehadeh et al. found the lowest value reported in the Table 4, of 795,000 oocytes in *M. cephalus* females from Hawaii [47].

This great variability of the values found for the fecundity of *M. cephalus* can be because of the difference in length and age of the studied organisms, as there is a positive relation between fecundity and bigger and older aged females, even in the same area.

Relative fecundity values obtained in this study were 50,272 oocytes per gram, ranged from 9,425 to 150,011, higher values than those obtained by Ibáñez and Gallardo-Cabello for *M. cephalus* in the Tamiahua lagoon, Veracruz of 1,680 oocytes per gram and a range of 680 to 4,776 oocytes [40].

It was observed that in the same study area as *M. cephalus*, *M. curema* showed a fecundity of 9,612 to 238,795 in females of 0 to 5 years of age and lengths of 10.54 cm to 27.79 cm, and an average relative fecundity of 1,120 oocytes per gram (850 to 1,176 oocytes per gram), far below the values of *M. cephalus*.

Conclusions

- Sex ratio was 0.88:1 males: females.
- Average length of sexual maturity (L_{50}) was 34.0 cm in both males and females with 4.64 years (males) and 4.98 years (females); average length of first maturity (L_{25}) for both was 30.0 cm corresponding to 3.4 years of age.
- The gonadosomatic index was at its maximum values in November, December and January. A second very small period occurs during September and October. Mature organisms occur throughout the year.
- The allometric relationship between the liver weight and the fish length is negative ($b=2.771$). Monthly values of the hepatosomatic index are higher in June, July and August
- The gastric repletion index shows its highest values in June, February and October.
- The condition factor reaches its highest values in June, August and December with Clark and Safran EW indexes and July,

Author	Area	Fecundity (oocytes)	Organism size
Thomson [65]	Australia	1'275,000-2'781,000	-
Kesteven [64]	Australia	1'275,000-2'781,000	-
Grant and Spain [60]	Australia	1'600,000-4'800,000	-
Tosh [47]	Australia	2'000,000-2'500,000	-
Jacob and Krishnamurthi [47]	India	1'320,000	50 cm (TL)
Tung [62]	Taiwan	700,000-3'000,000	-
Hsu [52]	Taiwan	700,000-3'000,000	-
Yand and Kim [47]	SW Korea	3'790,000	78.7 cm, 5 years old
Keithy Allardi [56]	Francia	500-2,800/gram	-
Popescu [47]	Black Sea: Danubian delta	5'065,800-5'085,440	-
Nikolskii [47]	Black Sea	3'089,000-7'206,000	-
Berg [47]	Black Sea	5'000,000-7'000,000	52 cm, 13 years old
Brulhet [47]	Mauritania	4'000,000-6'000,000	-
Landret [47]	Mauritania and Senegal	2'322,400	50 cm FL
Shehadeh [48]	Hawaii	340,000-795,000	induced spawning
Nash [47]	Hawaii	1'000,000 (effectively released)	-
Keith [47]	Hawaii	5'000,000-7'000,000 oocytes	-
Solis [63]	Tamaulipas, Mexico	1'341,000-2'919,000 oocytes (6,510 oocytes/g)	48 and 56 cm (TL)
Ibáñez-Aguirre and Gallardo-Cabello [40]	Veracruz, Mexico	405,767-898,512 (1,680 oocytes/g, 680-4,776)	-
This study	Central Mexican Pacific	1'422,076-1'747,736 oocytes (2,830 oocytes·g ⁻¹ , 1,500 - 2,900 oocytes·g ⁻¹)	28.5 cm to 48.8 cm (TL)

Table 4: Fecundity values by different authors and countries.

September, October and November with Fulton and Safran TW indexes.

- Total fecundity was 1'422,076 to 1'747,736 oocytes for females of 3 to 12 years old.
- Relative fecundity was average: 2,830 oocytes·g⁻¹ from 1,500 to 2,900 oocytes per female from 3 to 12 years old.
- Average oocytes diameter was 0.38 mm (from 0.22 to 0.52 mm).

Recommendations

The studies of the reproduction of the *Mugil cephalus* must be continued and published, because they are an important base line to compare if significant variations occur in the average size of sexual maturity (L_{50}) and at first maturity (L_{25}), which may indicate overexploitation of this resource.

Development of models of maximum sustainable yield and simulation capture should be taken into account to reach a rational management of this fishery, by capturing mature organisms that have already reproduced at least once and that will provide through recruitment new organisms to the population, preventing over-exploitation of the resource. Also, ban seasons should be imposed and the law obeyed as in the mesh size of the fishing gear, to assure that only adults will be fished.

Acknowledgement

We want to express our gratefulness to fishermen, and also EG Cabral-Solís, D Brambila-López and A Pérez-Muñoz that provided samples to complete the information of this study.

References

1. De Silva SS (1980) Biology of grey mullet: a short review. *Aquaculture* 19: 21-36.
2. Barletta M, Valenca D (2016) Biogeography and distribution of Mugilidae in the Americas. Crosetti & Blaber (ed.) pp: 42-63.
3. Harrison IJ (2002) Mugilidae. In: Carpenter K (ed.) FAO species identification Guide for fisheries purposes. The living marine resources of the Western Central Atlantic. Bony fishes Part 1 (Acipenseridae to Grammatidae). Rome FAO pp: 1071-1085.
4. Harrison IJ (1995) Mugilidae. In: Fischer W, Krupp F, Schneider W, Sommer C, Carpenter KE (eds.) FAO guide for species identification for purposes of Fisheries. Pacifico Centro Oriental, FAO, Roma pp: 1293-1298.
5. Whitfield AK, Panfili J, Durand JD (2012) A global review of the cosmopolitan flathead mullet *Mugil cephalus* Linnaeus 1758 (Teleostei: Mugilidae), with emphasis on the biology, genetics, ecology and fisheries aspects of this apparent species complex. *Reviews in Fish Biology and Fisheries* 22: 641-681.
6. SAGARPA (2015) Statistical Yearbook fishing 2014. National Commission of Aquaculture and Fisheries Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food.
7. Márquez-Millán R (1974) Observations on mortality totally growth in length of mullet (*Mugil cephalus*) in the lagoon Tamiahua, sea, México. INP, Scientific series 2: 1-17.
8. García S (1980) Contribution to the study of the fishery for mullet (*Mugil cephalus* L) in the lagoon Tamiahua, View. INP of the Ministry of Fisheries p: 28.
9. Díaz-Pardo E, Hernández-Vázquez S (1980) Growth, reproduction and feeding habits of the smooth *Mugil cephalus* in Laguna de San Andrés, Tamps. *Proceedings of the National School of Biological Sciences* 23: 109-127.
10. Romero MAS, Castro JL (1983) Aspects of the biology of mullet (*Mugil cephalus* Linnaeus) in the Dead Sea, Chiapas, Mexico. *An Esc Nac Cienc Biol, México* 23: 95-112.
11. Pérez-García M, Ibáñez AL (1992) Morphometry of fish *Mugil cephalus* and *M. curema* (mugiliformes: Mugilidae) in Veracruz, Mexico *Rev Biol Trop* 40: 335-339.
12. Ibáñez AL, Leonart J (1996) Relative growth and comparative morphometrics of *Mugil cephalus* L. and *M. curema* V. in the Gulf of Mexico. *Scientia Marina* 60: 361-368.
13. Ibáñez AL, Gallardo-Cabello M (1996a) Total and natural mortality of *Mugil cephalus* and *M. curema* (Pisces: Mugilidae), in Tamiahua Lagoon, Veracruz. I. Selectivity. *Hidrobiológica* 6: 9-16.
14. Ibáñez AL, Gallardo-Cabello M (1996b) Age determination of the grey mullet *Mugil cephalus* L. and the white mullet *M. curema*. V. (Pisces: Mugilidae) in Tamiahua lagoon, Veracruz. *Marine Science* 22: 329-345.
15. Sánchez-Rueda O, Mar IG, Aguirre ALI, García AM (1997) Sediment in the stomach contents of *Mugil cephalus* and *M. curema* (mugiliformes: Mugilidae) in the lagoon Tamiahua, Mexico. *Rev Biol Trop* 45: 1163-1166.
16. Briones-Ávila E (1992) Diagnosis of fishery mullet (*Mugil cephalus*) in Sinaloa. INP CRIP-Mazatlán. *Newsletter* 25: 44-51.
17. Briones-Ávila E (1998) Fishery biology *Mugil cephalus* in Agua Brava Lagoon, Nayarit, during 1992-1994. Master's Thesis. Autonomous University of Sinaloa, México.
18. Gallardo-Cabello M, Espino-Barr E, Cabral-Solís EG, Puente-Gómez M, Garcia-Boa A (2012) Study of the otoliths of *Mugil cephalus* (Pisces: Mugilidae) in Mexican Central Pacific. *J of Fish and Aqua Sci* 7: 346-363.
19. Espino-Barr E, Gallardo-Cabello M, Garcia-Boa A, Puente-Gómez M (2015a) Growth analysis of *Mugil cephalus* (Percoidei: Mugilidae) in Mexican Central Pacific. *Glob J Fish Aquac* 3: 238-246.
20. Ibáñez AL (2016) Age and growth of Mugilidae. In: Crosetti D and Blaber S (eds.) *Biology, Ecology and Culture of Grey Mulletv (Mugilidae)*. Taylor & Francis Group, Boca Raton, Fla, USA p: 539.
21. Espino-Barr E, Cabral-Solís EG, Gallardo-Cabello M, Ibáñez AL (2005) Age determination of *Mugil curema* Valenciennes, 1836 (Pisces: Mugilidae) in the Cuyutlán Lagoon, Colima, Mexico. *Intl J Zool Res* 1: 21-25.
22. Gallardo-Cabello M, Solís EGC, Espino-Barr E, Ibáñez AL (2005) Growth analysis of white mullet *Mugil curema* (Valenciennes, 1836) (Pisces: Mugilidae) in the Cuyutlán Lagoon, Colima, México. *Hidrobiológica* 15: 321-325.
23. Ibáñez AL, Cabral-Solís EG, Gallardo-Cabello M, Espino-Barr E (2006) Comparative morphometrics of two populations of *Mugil curema* (Pisces: Mugilidae) on the Atlantic and Mexican Pacific coasts. *Sci Mar* 70: 139-145.
24. Cabral-Solís EG, Espino-Barr E, Gallardo-Cabello M, Ibáñez AL (2007) Fishing impact on *Mugil curema* stock of multi-species gill net fishery in a tropical lagoon, Colima, Mexico. *J Fish Aqua Sci* 2: 235-242.
25. Cabral-Solís EG, Gallardo-Cabello M, Espino-Barr E, Ibáñez AL (2010) Reproduction of *Mugil curema* (Pisces: Mugilidae) from the Cuyutlán lagoon, in the Pacific coast of México. *Agricultural Research Advances* 14: 19-32.
26. Espino-Barr E, Gallardo-Cabello M, Cabral-Solís EG, Puente-Gómez M, Garcia-Boa A (2013) Otoliths analysis of *Mugil curema* (Pisces: Mugilidae) in Cuyutlán Lagoon, Mexico. *Agricultural Research Advances* 17: 35-64.
27. Fulton T (1902) Rates of growth of sea-fishes. *Sci Invest Fish Div Scot Rept* 21: 3720.
28. Clark F (1928) The weight-length relationship of the Californian sardine (*Sardina coerulea*) at San Pedro. *Fish Bull USA* 12: 22-44.
29. Safran P (1992) Theoretical analysis of the weight-length relationship in fish juveniles. *Mar Biol* 112: 545-551.
30. Sokolov VA, Wong M (1972) Research into pelagic fish in the Gulf of California (sardine, thread herring and anchovy) in 1970. *Series information* 1: 1-35.
31. Holden MJ, Raitt DFS (1975) *Manual Fisheries Science. Part 2: Methods for research and application resources*. ONU/FAO. *Tec Doc fisheries* 115: 1-207.
32. Aboussouan A, Lahaye J (1979) The potential of ichthyoplankton populations. Fertility and echthyoplankton. *Cybiurn* 6: 29-46.
33. Espino-Barr E, Vega AG, Hernández HS, Vega HG (2008) *Manual fisheries biology*. Autonomous University of Nayarit p: 168.
34. Sparre P, Venema SC (1995) *Introduction to the assessment of tropical fish stocks*. FAO Doc. Tec. Fishing, Roma p: 420.

35. Rodríguez-Gutiérrez M (1992) Techniques for quantitative assessment of gonadal maturity in fish p: 79.
36. Gaertne D, Laloe F (1986) Etudebiometrique the tiller a'premier maturity of sexuelle Geryonmaritae, Maning and Holthuis, 1981 Senegal. *Oceanologica Act* 9: 479-487.
37. Simpson AC (1951) The fecundity of the plaice. *Fishery Investigations*, London 18: 1-27.
38. Espino-Barr E, Gallardo-Cabello M, Cabral-Solís EG, Puente-Gómez M, Garcia-Boa A (2015b) Reproduction of *Gerres cinereus* (Percoidei: Gerreidae) off the Mexican Pacific coast. *Marine and Coastal Sciences Magazine* 7: 83-98.
39. Gallardo-Cabello M, Espino-Barr E, Garcia-Boa A, Puente-Gómez M, Cabral-Solís EG (2015) Reproduction of *Diapterus brevirostris* (Percoidei: Gerreidae) in the Mexican Pacific coast. *Glob J Fish Aquac* 3: 221-229.
40. Ibáñez AL, Gallardo-Cabello M (2004) Reproduction of *Mugil cephalus* and *M. curema* (Pisces: Mugilidae) from a coastal lagoon in the Gulf of Mexico. *Bull of Mari Sci* 75: 37-49.
41. Briones-Avila E (1990) The period of gonadal maturity in mullet (*Mugil cephalus* L.) in Sinaloa and Nayarit. *Beef. VIII Congreso Nacional Oceanografía. Mazatlán, Sinaloa. México.*
42. Briones-Avila E (1994) The regulation of the fishery smooth (*Mugil cephalus* and white mullet) in Sinaloa and Nayarit. *Res. IV National Congress of Ichthyology. Morelia, Michoacán.*
43. Render JH, Thompson BA, Allen RL (1995) Reproductive development of striped mullet in Louisiana estuarine waters with notes on the applicability of reproductive assessment methods for isochronal species. *Trans Am Fish Soc* 124: 26-36.
44. Hubbs CL (1921) Remarks on the life history and scale characters of American mullets. *Trans Am Microsc Soc* 40: 26-27.
45. Jacot AP (1920) Age, growth and scales characters of the mullet *Mugil cephalus* and *Mugil curema*. *Trans. Am Microsc Soc* 39: 199-230.
46. Arnold EL, Thompson JR (1958) Offshore spawning of the striped mullet, *Mugil cephalus*, in the Gulf of Mexico. *Copeia* 158: 130-132.
47. Oren OH (Ed) (1981) *Aquaculture of grey mullets*. International Biol Prog: 26, Cambridge Univ Press, Cambridge p: 507.
48. Scotton LN, Smith RE, Smith NS, Price KS, de Sylva DP (1973) Pictorial guide to fish larvae of Delaware Bay: with information and bibliographies useful for the study of fish larvae. *Delaware Bay Report Series*. College of Marine Studies, University of Delaware p: 205.
49. Honebrink R (1990) *Fishing in Hawaii: a student manual*. Education Program, Division of Aquatic Resources, Honolulu, Hawaii p: 79.
50. Chang CW, Tzeng WN, Lee YC (2000) Recruitment and hatching dates of grey mullet (*Mugil cephalus* L.) juveniles in the Tanshui Estuary of Northwest Taiwan. *Zoological Studies* 39: 99-106.
51. Shung SH (1977) Studies on the catch and fishery biology of *Mugil cephalus* in 1975. *Bulletin of Taiwan Fisheries Research Institute* 28: 123-133.
52. Hsu CC, Han YS, Tzeng WN (2007) Evidence of flathead mullet *Mugil cephalus* L. spawning in waters northeast of Taiwan. *Zool Stud* 46: 717-725.
53. Jeyaseelan MJP (1998) *Manual of fish eggs and larvae from Asian mangrove waters*. United Nations Educational, Scientific and Cultural Organization. Paris p: 193.
54. Marais JFK (1976) *The nutritional ecology of mullets in the Swartkops estuary*. PhD thesis, University of Port Elizabeth, Port Elizabeth.
55. Novikov NP, Sokolovsky AS, Sokolovskaya TG, Yakovlev YM (2002) *The fishes of Primorye*. Vladivostok, Far Eastern State Tech. Fish. Univ p: 552.
56. Keith P, Allardi J (2001) *Atlas freshwater fish France*. National Museum of Natural History, Paris. *Natural heritage* 47: 1-387.
57. Cardona L (2000) Effects of salinity on the habitat selection and growth performance of Mediterranean flathead grey mullet *Mugil cephalus* (Osteichthyes, Mugilidae). *Estuarine, Coastal and Shelf Science* 50: 727-737.
58. Kailola PJ, Williams MJ, Stewart PC, Reichelt RE, McNee A, et al. (1993) *Australian fisheries resources*. Bureau of Resource Sciences, Canberra, Australia p: 422.
59. Keith P, Vigneux E, Bosc P (1999) *Atlas freshwater fish France*. National Museum of Natural History, Paris. *Natural heritage* 39: 136.
60. Grant CJ, Spain AV (1975) Reproduction, growth and size allometry of *Mugil cephalus* Linnaeus (Pisces: Mugilidae) from north Queensland inshore waters. *Aust J Zool* 23: 181-201.
61. Yang WT, Kim UB (1962) A preliminary report on the artificial culture of grey mullet in Korea. In *Proc Indo-Pacif Fish Council* 9: 62-70.
62. Tung IH (1948) On the egg development and larval stages of the grey mullet, *Mugil cephalus* Linnaeus. *Rep Inst Fish Biol Minist Econ Aff Nat Taiwan Univ* 3: 187-215.
63. Solís RJM (1966) Fertility mullet (*Mugil cephalus* Linnaeus). *Inst Nal Inv Biol Pesq Sría. Ind y Com Trabajos de Divulgación* 11: 1-6.
64. Kesteven G (1942) Studies in the biology of Australian mullet. Account of the fishery and preliminary statement of the biology of *Mugil dobula* Günther. *Aust Council Sci Industr Res Bull* 157: 1-147.
65. Thomson JM (1963) Synopsis of biological data on the grey mullet (*Mugil cephalus* L.). C.S.I.R.O. Div Fish Oceanogr Sydney, Australia.