Reproduction of *Mugil curema* (Pisces: Mugilidae) from the Cuyutlán lagoon, in the Pacific coast of México

Reproducción de *Mugil curema* (Pisces: Mugilidae) de la laguna de Cuyutlán, en el Pacífico Mexicano

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Abstract

This paper deals with the reproduction of white mullet *Mugil curema* (Valenciennes, 1836) in the Cuyutlán lagoon, Colima State, México. Fish were obtained from local commercial fishery during one year. The male:female ratio was 0.63: 1.00. Berried females occurred all year round with two peaks: summer (August) and winter (January-February). Sexual maturation (L_{50}) of males and females was observed at a mean size of 270 mm and 255 mm corresponding to five and four years old, respectively. Minimum size of reproduction for males and females was 105 mm. The gonadosomatic index was higher during August and February. The allometric relationship with the hepatosomatic index was $LW = 6.00 \cdot 10^{-6} \cdot TL^{4.013}$. The condition factor indexes of Fulton and Safran showed an increment from December to March. Fecundity ranged from 9,612 to 238,795 oocytes for females between zero and five years old and mean relative fecundity was 1,120 oocytes$\cdot g^{-1}$ (850 to 1,176

Resumen

Se analizó la reproducción de la lebrancha o liseta *Mugil curema* (Valenciennes, 1836) en la laguna de Cuyutlán, Colima, México. La relación macho:hembra fue 0.63:1.00. Los peces fueron capturados durante un año. Se observaron hembras ovígeras todo el año, con dos picos: uno en verano (agosto) y otro en invierno (enero-febrero). Los machos y las hembras mostraron características de madurez sexual (L_{50}) a la talla promedio, de 270 mm, y de 255 mm, que corresponden a cuatro y cinco años de edad, respectivamente. La talla mínima de reproducción en machos y hembras fue 105 mm de longitud total. El índice gonadosomático fue más alto en agosto y febrero. La relación alométrica del índice hepatosomático fue $LW = 6.00 \cdot 10^{-6} \cdot TL^{4.013}$. Los factores de condición de Fulton y Safran se incrementaron de diciembre a marzo. La fecundidad varió, de 9,612 a 238,795 ovocitos en hembras de cero a cinco años de edad, y la fecundidad relativa promedio fue de 1,120 oocitos$\cdot g^{-1}$ (850

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ISSN 0188789-0

oocytes·g^{-1}). Results suggest a ban season from June 15th to September 15th, and the use of regulated mesh size on the gill net of 2 ¾ inches.

Key words

Fecundity, maturity period, fish reproduction, minimum spawning size, white mullet, *Mugil curema*.

a 1,176 ovocitos·g^{-1}). Los resultados sugieren establecer una temporada de veda del 15 de junio al 15 de septiembre, y el uso del tamaño de malla reglamentario, que es de 2 ¾ pulgadas, en las redes agalleras.

Palabras clave

Fecundidad, periodo de madurez, reproducción en peces, talla mínima de desove, lebrancha o liseta blanca, *Mugil curema*.

Introduction

Mugil curema (Valenciennes, 1836) is essentially an American species found in both; the Atlantic and Pacific oceans, with few populations in African waters (Álvarez-Lajonchere, 1976; Ibáñez-Aguirre and Gallardo-Cabello, 2004; Heras *et al*., 2009). Commercial catching of white mullet in the Mexican Pacific coast in 1999 reached 219 metric tons, from which 98 metric tons were reported for Colima state (SEMARNAP, 2000). According to Cabral-Solís (1999), *M. curema* is the second most important fishery (after shrimp) in Cuyutlán Lagoon, and its local fishery depends on more than 400 fishermen. In spite of its very low price (i.e. 15 to 18 pesos at the popular market, the equivalent to one and half American dollars), the white mullet represents an excellent protein source for residents, and work opportunity for the lagoon communities.

For this reason and also because of the commercial value of the white mullet roe, this species must be regulated. Currently the closed season for the area is from May 15th to July (DOF, 1995) established in 1987. However, this closed season should be reviewed in order to protect the reproductive period of this species.

In order to contribute to the knowledge of this important resource, in the present paper, aspects of the reproduction cycle of *M. curema* in the Cuyutlán lagoon in Colima State were analyzed. This study will provide basic information to regulate the fishery, suggesting a ban season, minimum fishing sizes and mesh opening for the gill net. This will avoid the capture of young specimens that have not reproduced yet.

Materials and Methods

The specimens were obtained from the commercial fishery in the Cuyutlán Lagoon (103º 57' and 104º 19' W; 18º 57' and 19º 50' N). The fishing gear used was a gill net of 2.5 inches mesh (6.35 cm). Samples were obtained monthly from March 1997 to February 1998. Total length was measured to the nearest mm (from the snout tip to the caudal fin extreme) for 4,482 organisms. The size of the sample was determined according to Daniel (2008).

The subsample of 579 specimens was used to cover the following data: total length (TL, mm) to ± 1 mm, total weight (TW, g), eviscerated weight (EW, g), liver weight (LW, g) and gonad weight (GW, g) to ± 1 g.

Sex and gonad maturation were determined *in visu*, on fresh organisms taken to the laboratory the same day they were caught. The stages of sexual maturity were determined using the key by Díaz-Pardo and Hernández-Vázquez (1980) where stage I is juvenile fish; in stage II gonads fill 1/3 of the abdominal cavity; in stage III gonads occupy ½ to ¾ of the abdominal cavity and oocytes are not individualized; in stage IV, pre-spawning stage, gonads occupy ¾ of the entire abdominal cavity and oocytes are individualized; stage V is the spawning stage where gonads occupy the total abdominal cavity and oocytes and semen can be released by squeezing the body; stage VI is post-spawning. The TL at first spawning for males and females was determined by using 50% of the accumulative frequency (L_{50}) of stages IV and V of sexual maturation (Sparre and Venema, 1995).

Also the minimum TL at first spawning was also recorded to be compared with other authors findings. The gonadosomatic index (GSI) for females and males was calculated according to Rodríguez-Gutiérrez (1992), where gonad weight (GW) is expressed as a function of body weight: GSI = 100·GW/TW (TW = total weight). As a measure of physical fitness of the fishes, we obtained the condition factor $K = (EW \cdot TL^{-3})*100$ (Clark, 1928), $K = (TW \cdot TL^{-3})*100$ (Fulton, 1902) and $a = TW \cdot TL^{-b}$ (Safran, 1992), the hepatosomatic index (HSI), expressed as the percentage of liver weight (LW) with respect to the total weight HSI = 100·LW/TW (Rodríguez-Gutiérrez, 1992).

Mean monthly samples were compared through variance analysis of HSI and K, which assumes normal conditions and equal variances. If variances among sampled groups were equal, then the respective means could be compared through parametric variance analysis (Sachs, 1978). With this in mind, the Levene test of equal variances was used on sample groups of different sizes. If the data did not meet the assumptions despite mathematic transformations, the non-parametric Kruskal and Wallis analysis (Zar, 1996) was used under the null hypothesis that there were no significant differences ($P < 0.05$) in monthly variances. When the null hypothesis was rejected, the non-parametric multiple comparisons Dunn's test was used (Zar, 1996).

Fecundity (F) and relative fecundity were obtained by the gravimetric method using the wet weight of 34 stage V female gonads of *M. curema*. To estimate total fecundity, two subsamples of approximately 500 oocytes were obtained. The following expression was used in the calculation: $F = n * p/P$, where F = relative fecundity; n =

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ISSN 0188789-0

number of oocytes in the subsample; P = average weight of the subsample in grams and p = weight of all the oocytes in grams (Kartas and Quignard, 1984). The relationship between fecundity, total length and weight was calculated with the formula $F = a \cdot x^b$ where F= fecundity, x = individual weight or length, a = origin ordinate or initial number of ovocites, b = trend or oocite number changing rate.

The relationships among TL, TW, LW, testis weight (TeW), ovary weight (OW), and fecundity were defined for different ages. Age groups were obtained by sagittal otolith analysis; six age groups of *M. curema* were established by Espino-Barr *et al.* (2005) and Gallardo-Cabello *et al.* (2005).

Results

The sample size was statistically sufficient (P < 0.05) in every month (Table 1).

Table 1. Gonadosomatic index variance analysis per intervals by Kruskal-Wallis one way method.*

Month	n_i	Median	Media	Std Dev	Std Error	R_i average
March	50	0.406	0.899	1.371	0.194	242.7 [abc]
April	45	0.541	1.085	1.313	0.196	308.8 [bc]
May	50	0.548	1.028	1.618	0.229	305.9 [bc]
June	41	0.380	0.595	0.590	0.092	215.8 [ab]
July	50	0.559	0.857	1.384	0.196	286.9 [abc]
August	50	0.628	2.002	2.755	0.390	335.6 [c]
September	50	0.264	0.622	0.850	0.120	175.1 [a]
October	45	0.355	0.643	1.070	0.159	209.5 [ab]
November	50	0.576	1.472	2.482	0.351	299.4 [bc]
December	50	0.527	0.858	1.172	0.166	297.3 [bc]
January	48	0.829	1.965	2.597	0.375	354.9 [cd]
February	50	1.519	2.865	3.547	0.502	431.3 [d]

*Same letters mean that there is no difference among months; different letters mean statistical difference among months.

Gonads were visually differentiated, except in young individuals that had never spawned. Ovaries were cylindrical and, when mature, oocytes were intense yellow and easily recognized. Table 2 shows mean values of the gonad weight (GW) for each age group of *M. curema.* Also results on TL, TW and F.

Testes were elongated, whitish in color and smaller than ovaries. Their mean weights per age are shown in Table 2. In *M. curema* ovaries weigh up to 10.32 g in three year old specimens of 230 mm TL, while testis weight 6g in a same size specimen.

Fecundity values ranged from 9,612– 238,795 oocytes for females between zero and five years, measuring 10.54 to 27.79 cm, and weighing 11.3 to 203.10 g. Fecun-

ISSN 0188789-0

dity for minimum length of spawning (0 years) was 9,612 oocytes (Table 2). Mean relative fecundity value for this species was 1,120 oocytes·g^{-1} (range = 851 to 1,176 oocytes·g^{-1}).

Table 2. Length (TL, cm), weight (TW, g), liver (LW, g), testis weight (TeW, g), ovary weight (GW, g) and fecundity (number of oocytes) for each age group (years).

Age	TL (cm)	TW (g)	LW (g)	TeW (g)	GW (g)	F (eggs)
0	10.54	11.30	0.076	4.873	0.070	9,612
1	15.63	36.57	0.372	5.438	0.866	35,488
2	19.73	73.25	0.948	5.802	3.847	76,827
3	23.03	115.98	1.761	6.056	10.319	128,079
4	25.67	160.33	2.724	6.241	20.681	183,595
5	27.79	203.10	3.745	6.381	34.356	238,795

The sample size of 579 individuals of *M. curema* analyzed to determine sex ratio was 219 (38.56.0%) males and 349 (61.44%) females and 11 juveniles, with a male:female ratio of 0.63:1.00.

Monthly variation in the relative frequency of gonad maturation stages (Fig. 1) show that during March, April and May stage II predominated in females 54%, 47% and 50%, compared to 18%, 13% and 14%, respectively in males. During May and June the number of organisms in phases III and IV increased, and although stage V is not shown during these months, there were 12% and 4% of spawned females and males (stage VI), respectively. The highest percent of individuals in stage I (15%) was observed in June, due to the recruitment of young fish. The highest percent of individuals in spawned stage (VI) was observed in July, females 60% and males 24%, (with phase V only 2%) and phase V (22%) was observed in August. During September females and males appeared again in a high number in stage II, 50% and 20% respectively, but also organisms in other maturity stages could be observed. The next months showed organisms in phases II to VI, with an important presence of stage V in January and February (16% of the females). The presence of organisms in phase VI, spawned during most of the year (except March and April) indicates that the species spawns year round, with two important peaks: August and January-February.

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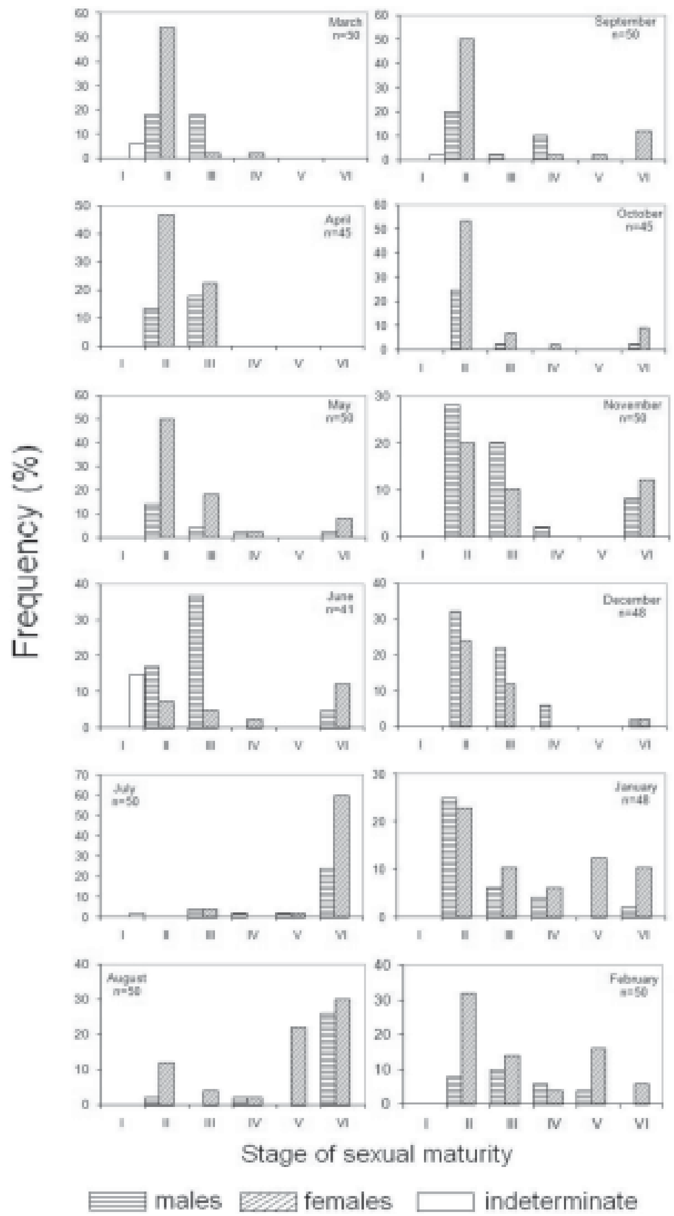
ISSN 0188789-0

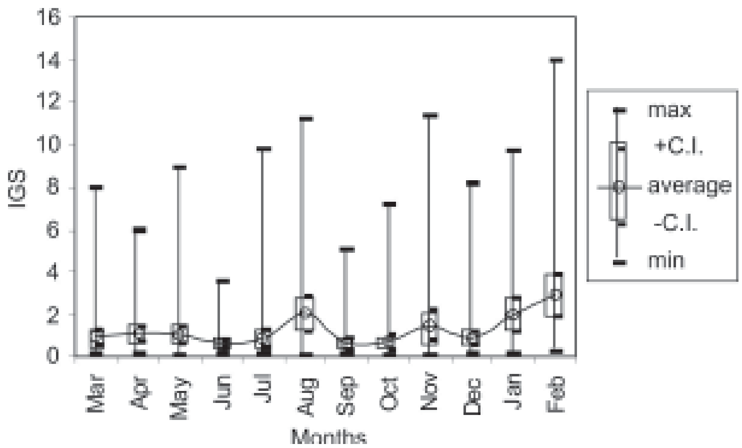
Figure 1. Monthly variation of sexual maturity in males and females of *M. curema*.



The length at first maturity (L_{50}) for females was 255 mm which corresponds to four years of age, and for males 270 mm, at five years.

The gonadosomatic index (GSI) was <1 during six months of the year for *M. curema* (Fig. 2). Ovary and testis maturation started in January and June, reaching the highest GSI values in two periods: August (GSI = 2.002) and February (GSI = 2.865) and decreasing in September (GSI =0.622) and June (GSI = 0.595), respectively.

Figure 2. Monthly variation of gonadosomatic index (GSI), average, maximun and minimum data and the confidence interval (C.I.).



In the pre-spawning stage, gonads fill ¾ of the abdominal cavity; ovaries are a yellowish color and eggs can be seen individually. Testes are entirely white. Organisms in post spawned stage were seen throughout the year, except March and April; gonads are soft and vascularized and can fill half of the abdominal cavity. Ovaries turn pinkish and show a milky yellowish fluid where the eggs cannot be individually identified. Testes have a milky whitish color. According to Kruskal-Wallis' analysis, January and August were significantly different from September, October and June. February was different to all the other months except August and January; during those months a higher number of organisms had heavier gonads and were spawning (Table 1).

The allometric relationship of the hepatosomatic index (HSI) was: $LW = 6.00 \cdot 10^{-6} \cdot TL^{4.013}$. The allometric index (b) value indicated that liver weight increases in a greater proportion than the cube of length; it is a positive allometric index, so there is a positive dependence between TL and LW (Table 3).

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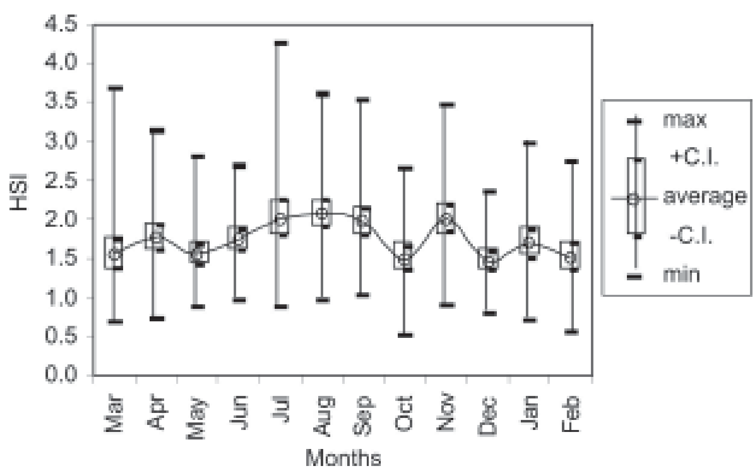
Table 3. Hepatosomatic index variance analysis per intervals by Kruskal-Wallis one way method.

Month	ni	Median	Media	Std Dev	Std Error	R_i average
March	50	1.550	1.548	0.668	0.095	274.3^{abc}
April	45	1.456	1.763	0.527	0.079	233.6^{a}
May	50	1.475	1.546	0.428	0.061	231.2^{a}
June	41	1.676	1.735	0.426	0.067	303.2^{abc}
July	50	1.511	2.014	0.756	0.107	238.7^{ab}
August	50	1.667	2.072	0.566	0.080	301.0^{abc}
September	50	1.936	1.970	0.600	0.085	349.5^{bc}
October	45	1.993	1.495	0.524	0.078	386.4^{c}
November	50	1.817	2.012	0.634	0.090	352.6^{c}
December	50	1.498	1.470	0.417	0.059	229.0^{a}
January	48	1.987	1.687	0.615	0.089	361.9^{c}
February	50	1.406	1.519	0.585	0.083	215.2^{a}

*Same letters mean that there is no difference between months; different letters mean statistical difference between months.

Variations of HSI throughout the year are shown in figure 3; the largest range from minimum to maximum values was in August, and the highest percentage of organisms in the median value. This month is also the same period of time of the reproductive process. The liver accelerates the synthesizing process of lipid reserve and its weight increases during the spawning period.

Figure 3. Monthly variation of hepatosomatic index (HSI), average, maximum and minimum data, and confidence interval (C.I.).



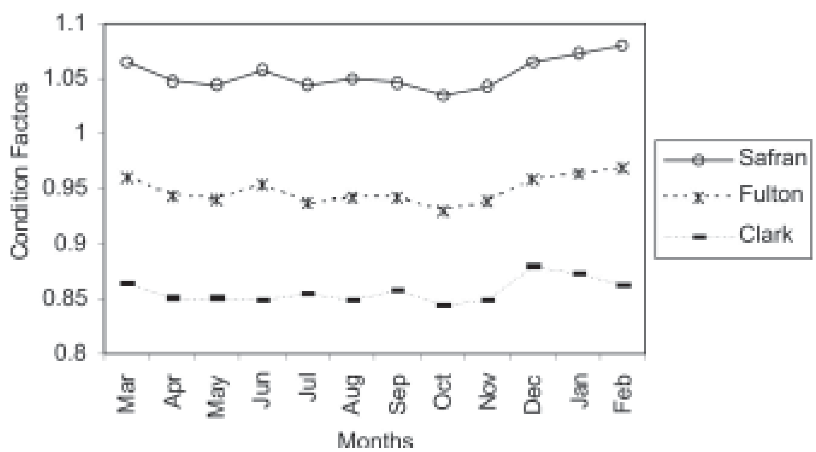
The variance null hypothesis (H_0) establishes equality between average values and it was rejected, also significant statistic differences were found using the Dunnett test of multiple comparisons was H=72.568 and 11 gl (P=<0.001).

According to the Kruskal-Wallis' analysis, February, December, May and April have significant statistic differences compared with October, January, November and September.

July had significant differences with October, January and November, probably because it is the month with most post spawned organisms (Table 3).

The condition factor of Fulton and Safran indexes increased in February and August. Clark's index (with eviscerated weight) decreased due to corporal waste (Fig. 4).

Figure 4. Monthly values of the condition factor using the methods of Fulton (1902), Safran (1992) and Clark (1928).



Discussion

The highest growth rate in length in *M. curema* takes place in the age groups of cero to two years, after which growth in length diminishes and total weight and gonad weight increases, as do the fatty acid reserve. This exemplifies two periods during the life cycle of this species: the first, when most of the energy from feeding is used in the length growth and to help reduce natural mortality by depredation and interspecific competence; and the second period, when most of the energy is focused on the fatty acid reserve and formation of sexual products for reproduction (Fig. 5) (Rodríguez-Gutiérrez, 1992; Espino-Barr *et al.*, 2008).

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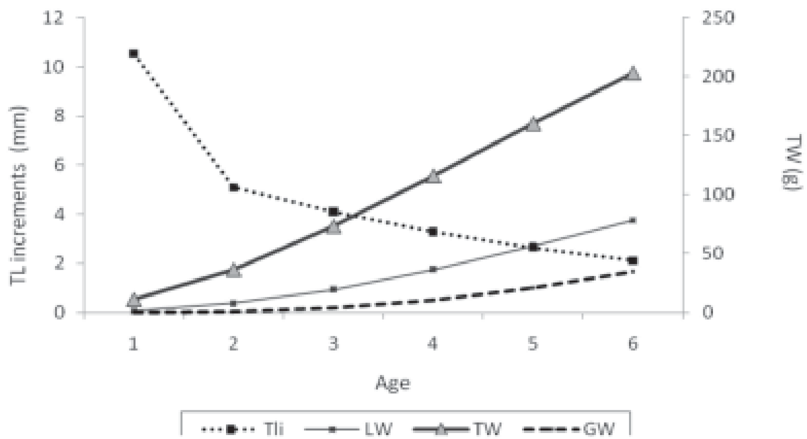
Figure 5. Relationship between age and total length increment (TLI), Total weight (TW), liver weight (LW) and Gonad weight (GW) in *Mugil curema*.



M. curema spawns mainly during early spring or summer in several places of the Atlantic and Pacific oceans (Table 4). Nevertheless, in the present study we observed two maximum periods: one in summer (August) and another in winter (February). Similar results were obtained by Álvarez-Lajonchere (1976) for this species in the coast of Cuba.

Table 4. Spawning period for *Mugil curema*. (As in Ibáñez-Aguirre and Gallardo-Cabello, 2004, and augmented).

Area	Period	Authority
Atlantic (W)	April-August, maximum in May	Jacot (1920)
Florida (S)	March-April	Anderson (1957)
Gulf of Mexico	April-May	Oren (1981)
Texas	Spring-early Summer	Moore (1974)
Venezuela	July	Rojas (1972)
Venezuela	July-August	Edimar (1973)
Cuba	June-August and November-January	Álvarez-Lajonchere (1976)
Brazil	March-August	Maia and Vilela do Nascimento (1980)
Gulf of Mexico	February-May	Ibáñez-Aguirre and Gallardo-Cabello (2004)
Mazatlán	May-July	Briones (1981), in Vasconcelos-Pérez *et al.* (1996)
Oaxaca	May-August	Ramos-Cruz (1986), in Vasconcelos-Pérez *et al.*(1996)
Cuyutlan Lagoon, Colima	August and February	this study

The minimum spawning age observed in this study was before the first year of age when the species reaches its gonadic maturity (Table 5). This differs from observations by other authors, who reported ages of one year (Ibáñez-Aguirre and Gallardo-Cabello, 2004).

Table 5. Minimum length (mm) at first spawning of females of *Mugil curema*. TL = Total length.

Area	TL (mm)	Age (year)	Authority
Florida (S)	209	1	Anderson (1957)
Venezuela	303	1	Edimar (1973)
Gulf of Mexico	208	1	Ibáñez-Aguirre and Gallardo-Cabello (2004)
Cuyutlán Lagoon, Colima	105	0	this study

Gonadosomatic index values of *M. curema* in Cuyutlán are higher (GSI=17) compared to those obtained in Tamiahua lagoon, of GSI=12 (Ibáñez-Aguirre and Gallardo-Cabello, 2004).

The hepatosomatic index calculated in Cuyutlán and Tamiahua lagoons have an alometric relation with the specimen's weight: in Cuyutlán it is b=4.013 and in Tamiahua b=3.64 (Ibáñez-Aguirre and Gallardo-Cabello, 2004). According to the monthly values, the liver accelerates its lipid reserve synthesizing function and its weight is considerably increased at spawning. This species accumulates fatty acids in its celomic cavity, which can be seen in the phases of maturity prior to spawning and it reaches its maximum values when the gonad fills the entire abdominal cavity.

The condition factor of Fulton (1902) and Safran (1992) indexes show an increment in February and August, months when spawning takes place and gonads reach their highest weight. The opposite occurs with Clarkum:'s index (which considers eviscerated weight): body weight decreases due to corporal waste during the reproductive period.

Fecundity values ranged from 9,612 to 238,795 oocytes for females measuring 10.54 to 27.79 cm. These values are the lowest calculated for this species in the coasts of México. Vasconcelos-Pérez *et al.* (1987) reported 283,000 in organisms of 22 to 27 cm in Pueblo Viejo Lagoon, Veracruz. Ibáñez-Aguirre and Gallardo-Cabello (2004) found values of 51,901 to 346,701 eggs in females of 18.7 to 32 cm in Tamiahua Lagoon, Veracruz.

Higher numbers were reported by Ramos-Cruz (1986) in the coast of Oaxaca (780,787 eggs in females 29 cm TL) and Villaseñor and González (1990) found 954,900 eggs in the coast of Nayarit. In Cuba, Álvarez-Lajonchere (1982) reported values of 295,081 to 488,956 eggs in organisms of 28.4 to 34.1 cm total length in different localities of the island.

The value of relative fecundity found in this study (1,120 oocytes·g^{-1}) is lightly higher than the one reported in Tamiahua lagoon (1,064 oocytes·g^{-1}) by Ibáñez-Aguirre and Gallardo-Cabello (2004). Edimar (1973) reported in the Restringa lagoon, Venezuela a value of 1,369 oocytes·g^{-1} for the same species. Orozco-Álvarez (1986) found much higher values in De la Mancha Lagoon in Veracruz (11,245 oocytes·g^{-1}).

Differences found in these values of fecundity can be explained by the fact that each place can have different lengths at which females mature. It can also be due to the method used to determine number of eggs in the gonad. Kartas and Quignard (1984) reported that fecundity values in bony fishes have a high variability.

Gallardo-Cabello *et al*. (2005) found that *M. curema* of Cuyutlán have lower values of $L\infty$ and higher k index of the growth equation than the same species in Tamiahua lagoon. Therefore the same species will have smaller size at the same age and shorter longevity in the first place than in the second. This is related to the phenomena explained by Taylor (1958; 1960), who found that the k index of the growth equation is inversely proportional to latitude and temperature. Cuyutlán lagoon is located closer to the equator than Tamiahua lagoon; its temperature ranges from 17.5ºC to 34.2ºC while the range in Tamiahua is from 10.3ºC to 33ºC.

Although *M. curema* from Cuyutlán is smaller in size than in Tamiahua, its relative fecundity is higher, and it has two reproduction periods, i.e., summer and winter while in Tamiahua there is only one reproductive period. *M. curema* spawns at a smaller size (105 mm) in Cuyutlán (minimum size of reproduction).

Approximately 29% of the catch is accounted by immature fish based on average size of capture (290.8 cm) in one of the most common mesh sizes of 6.35 cm gill net (Cabral-Solís *et al*., 2007). This could adversely affect natural recruitment. Gill nets with a larger mesh size can remove this potential constraint.

With the biological data mentioned we suggest a modification of the established ban season from May 15th to July (DOF, 1995), to the period from June 15th to September 15th.

Fishers should change their gill nets from a mesh size of 2 ¼ inches which they use currently to the legal size of 2 ¾ inches or bigger which will protect young organisms that have not yet reproduced.

M. curema has a high adaptive potential to different habitats an ecologic niche, considering these results and those for Tamiahua lagoon (Ibáñez-Aguirre and Gallardo-Cabello, 2004).

Our results are valid even if they are from 1997-1998, the population characteristics do not vary too much; Gallardo-Cabello *et al.* (2006) observed that data on age (by scale reading) did not differ from that determined by length frequency by Cruz-Romero *et al.* (1993). It is always better to have some information on the population being fished throughout time, than no register at all.

Conclusions

Mugil curema reaches a higher fecundity in Cuyutlán than in Tamiahua, although its size is smaller.

In Cuyutlán lagoon *M. curema* presents a longer reproductive season extended the whole year round with two maximum peaks: one in August and the other in January-February. Male and females mature at 0 years of age.

It is important to establish a fishing ban from the 15th of June to the 15th of September and the use of the official mesh size of 2 ¾ inches.

The fishery should be monitored to learn about the changes in the biological aspects of *M. curema*.

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Recibido: Diciembre 3, 2009
Aceptado: Octubre 7, 2010