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Research Article

Juvenile growth of white mullet *Mugil curema* (Teleostei: Mugilidae) in a coastal lagoon southwest of the Gulf of California

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ABSTRACT. Otolith microstructure was used to determine the age and evaluate the growth of juvenile white mullet (*Mugil curema*) during their residence in the coastal lagoon El Conchalito, B.C.S., Mexico, from May 1997 to May 1998. Juveniles were sampled monthly during the full and ebbing phases of the maximum high tide. The juveniles studied were between 16 and 42 mm standard length (SL) and from 22 to 109 days old. The Gompertz growth model appropriately described the relationship between age and SL (r^2 = 0.94). The average growth rate was 0.29 mm d^{-1} between 20 and 110 days of age, which was lower than the growth rate of the juveniles prior to entering the lagoon. This suggests that growth is faster along the coast than in the lagoon. The strategy of entering protected areas allows individuals to reach a size that maximizes escape from predators and, therefore, the probability of survival when reentering the coastal habitat.

Keywords: *Mugil curema*, juveniles, age, otoliths, coastal lagoon, Gulf of California, Mexico.

Crecimiento de juveniles de la lisa blanca *Mugil curema* (Teleostei: Mugilidae) en una laguna costera del suroeste del golfo de California

RESUMEN. Utilizando la microestructura de los otolitos se determinó la edad y se evaluó el crecimiento de juveniles de lisa blanca *Mugil curema* durante su permanencia en la laguna costera El Conchalito, B.C.S., México, de mayo de 1997 a mayo de 1998. Los juveniles se recolectaron durante la fase estacionaria y de descenso de la máxima pleamar de cada mes. Durante el estudio, se analizaron juveniles de 16 a 42 mm de longitud estándar (LE) con edad entre 22 y 109 días. El modelo de Gompertz describió adecuadamente la relación entre la edad y LE (r^2 = 0,94). La tasa promedio de crecimiento entre 20 y 110 días de edad fue de 0,29 mm $día^{-1}$, menor que la tasa de crecimiento de los juveniles antes de incorporarse a la laguna. Esto sugiere que el crecimiento es más rápido en la costa que en la laguna, y la estrategia de introducirse a zonas protegidas es para alcanzar una longitud que maximice el escape a la depredación y maximice la probabilidad de supervivencia cuando se reincorporen al ambiente costero.

Palabras clave: *Mugil curema*, juveniles, edad, otolitos, laguna costera, golfo de California, México.

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INTRODUCTION

The white mullet, *Mugil curema* (Valenciennes, 1836) is distributed along both coasts of the American Continent. In the Pacific, it is found from the gulf of California to Chile (Harrison, 1995). Mullet of the genus *Mugil* are common fish in artisanal fishing in temperate and tropical regions, and are captured in reef areas, tidelands, and along shallow beaches using seines and gillnets of different size mesh (Chávez, 1993).

Along the west coast of the gulf of California, white mullet spawns all year with a peak from April to July (Chávez, 1985). The early larvae are characterized by dark body pigmentation, which may be an adaptation to high levels of ultraviolet radiation at the sea surface (Powles, 1981). Spawning take place off the coast and the juveniles then enter estuaries and coastal lagoons by following turbid gradients generated by tidal currents (Blaber, 1987), where they remain for several months (Yáñez-Arancibia, 1976; González-Acosta *et al*., 1999; Quiñonez-Velázquez &

Mendoza-Guevara, 2009). The movement of the juveniles toward shallow areas reduces fish predation and gives them conditions for better growth and survival (Blaber, 1987).

According to Mexico's Statistics Yearbook for Fisheries, the catch of mullets is included under "Lebrancha" and "Lisa" categories. In the Mexican Pacific coast, Lebrancha is only used in the southern part and represent less than 5% of the Pacific catch. In these categories the most important species are *M. cephalus* and *M. curema*. The Mexican Pacific catch of mullets averaged 3,690 t wet weight during 1996 to 2007 (Anónimo, 2007). From that catch, more than 75% was obtained in the Gulf of California (Sinaloa, Baja California Sur, Nayarit and Sonora).

Individual growth in species of the family Mugilidae is rapid; they reach in average 17 to 23 cm length and sexual maturity during the first year of life (Yáñez-Arancibia, 1976; Martin & Drewry, 1978; Ibañez-Aguirre & Gallardo-Cabello, 1996; Gallardo-Cabello *et al*., 2005). In the Mexican Pacific, the age during the adult stage of the white mullet has been estimated by using scales and otholits (Ibañez-Aguirre & Gallardo-Cabello, 1996; Gallardo-Cabello *et al*., 2005), and using the von Bertalanffy growth model differences in growth by gender were identified, the females have larger sizes by age than males. During the early stage of the development of this species, Marin *et al*. (2003) analyzed the recruitment on the coasts of Venezuela using the otolith microstructure. Our objective was to evaluate growth rates of juvenile white mullet *M. curema* during their residency in El Conchalito lagoon on the southwest coast of the gulf of California.

MATERIAL AND METHODS

Juvenile white mullet *M. curema* were sampled monthly, from May 1997 to May 1998, at the mouth of El Conchalito lagoon (Fig. 1), during the maximum height and ebb of the highest tide of the month. To catch the greatest size range of juveniles in the lagoon, three types of nets were used; a fixed flume net 30 m long, 1.5 m high, with a central cod-end 4 m long with 6 mm mesh; and two seine nets 15 m long, 1.5 m high, with a central cod-end 2 m long one with 6 mm and one with 3 mm mesh. Water surface temperature was recorded using a Horiba U-10 portable analyzer during each sampling period.

Sampled fish were placed in labeled polyethylene bags and put on ice then transported to the laboratory, where white mullet were separated from the rest of the sample and preserved in 96% alcohol. Fish were identified at the species level using a morphological key (Harrison, 1995; Traper *et al*., 2009). For each monthly sample a random subsample was selected of up to three juveniles of each 0.5 mm standard length (SL) interval. The otoliths sagitta of each of these fish were extracted and mounted on a glass slide using instant glue. For age determination, the right otolith was used. To make the growth increments in the otoliths evident, we ground them on the sagittal plane using sandpaper of 0.2 to 12 µm grit size.

Growth increments were counted independently by two readers without knowledge of size and sampled date for the individuals. We used the approach that the hatching mark is the first one deposited close to otolith nucleus, it was not included in the count, and that growth increments are daily deposited according to the results of Radtke (1984) for the striped mullet (*M. cephalus*). The same approach was used by Marin (1996). The index of the average percentage error (IAPE) was used to evaluate the precision of the age determinations (Beamish & Fournier, 1981), the index was calculated by the formula:

$$\mathrm{IAPE} = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{X_{ij}-X_j}{X_j}\right]$$

where N is the number of fish aged, R the number of times each was aged, Xij is the ith age determination of the jth fish, and Xj is the average age calculated for the jth fish.

The Gompertz curve model was used to describe the growth of the juvenile white mullet, because this model is more appropriate than the logistical curve and that of von Bertalanffy in describing the growth of fish < 1 year (Zweifel & Lasker, 1976; Ricker, 1979; Gluyas-Millán *et al*., 1998; Quiñonez-Velázquez *et al*., 2000):

$$SL_t = SL_0 e^{k(1-e^{-at})}$$

where SL_t: length to the age t, SL_0: length at t: 0, k = a dimensionless parameter, such that ka = A_0 is the specific growth rate at t = 0, ($A_t = A_0 e^{-at}$), a: specific rate of growth, when t = t_0, t_0: age when the growth rate starts to decrease, the main the inflection point of the curve (Ricker, 1979).

The parameters of the model were estimated using the module NONLINE of the computer program STATISTICA (StatSoft, 1995). The instantaneous growth rate G (mm d^{-1}) was calculated using the SL estimated for 5-d age intervals:

$$G = (SL_{t+1} - SL_t)/5$$

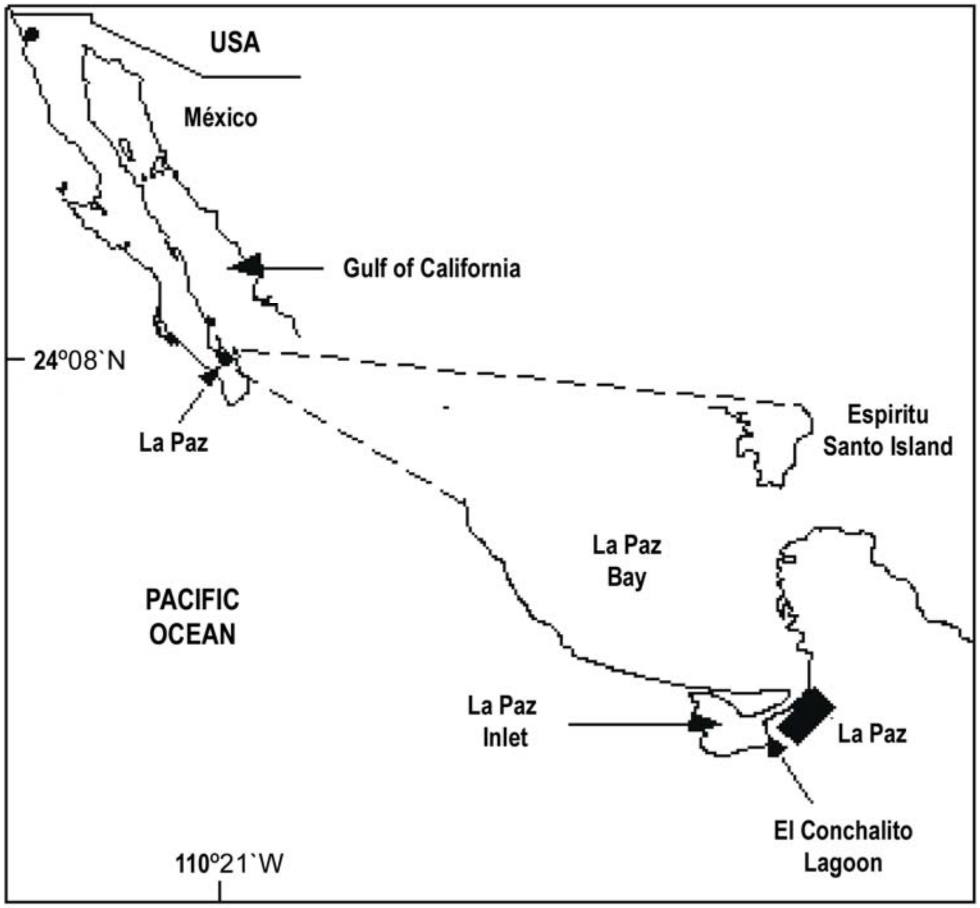

Figure 1. Location of the study area. El Conchalito Lagoon is part of La Paz Bay, located on the southwest margin of the gulf of California.

Figura 1. Localización del área de estudio. La laguna El Conchalito es parte de la bahía de La Paz, localizada en el margen suroeste del golfo de California.

RESULTS

From May 1997 to May 1998, 1,019 juvenile white mullet *M. curema* ranging from 16 to 42 mm SL were sampled (Table 1). More individuals were caught from December 1997 to May 1998. The length frequency of the juvenile white mullet showed two groups of juveniles with an increasing trend in average length over time (Table 1, Fig. 2). The first group occurred from May to September 1997 and the second group from October 1997 to May 1998. The average length ranged between 26-34 mm for the first group and 23-32 mm for the second group, ($F = 0.26$, $P > 0.05$). The average water surface temperature (WST) during the study ranged from 18 to 32°C, no relationship was detected between the average of WST and the average of standard length of the juvenile (Spearman correlation, $r = 0.36$, $P > 0.05$). Juveniles with the smallest average SL occurred during July 1997 and February 1998 when juveniles < 24 mm SL were caught, the WST in those months were among the highests and lowest values.

The juvenile subsample used for age determination (n = 254) was 25% of the total (Table 1). The otolith microstructure showed alternate opaque and trans-lucent zones that represent daily growth increments (Radtke, 1984). The low value of the IAPE (4.3%) indicated high precision in the ageing (Campana *et al*., 1995).

Average age of the juveniles varied from 47 to 81 days. The relationship between maximum otolith diameter and SL had a good fit, $r^2 = 0.88$. The close relationship of these two variables justifies the use of the otolith in the age determination and in the description of the growth of the white mullet and is consistent with results of others studies (Radtke, 1984).

Table 1. Interval and average of standard length and age of the juvenile white mullet (*Mugil curema*) sampled in El Conchalito Lagoon, May 1997 to May 1998.

Tabla 1. Intervalo y promedio de la longitud estándar de juveniles de lisa (*Mugil curema*) recolectados en la laguna El Conchalito, mayo 1997 a mayo 1998.

Date	Temp	Juvenile		Interval		Average	
	(°C)	Total sample	Age sub-sample	SL (mm)	Age (days)	SL (mm)	Age (days)
23-May-97	25.8	34	18	24.7-40.8	55-76	28.1	63
29-Jun-97	29.4	-	-	-	-	-	-
20-Jul-97	30.4	21	11	16.6-36.9	28-90	25.9	56
19 Aug 97	31.5	27	15	22.9-37.6	43-86	29.1	66
17-Sep-97	31.8	5	5	29.1-36.9	67-91	33.9	81
18-Oct-97	28.1	31	13	24.8-32.3	52-75	28.0	64
15-Nov-97	24.4	46	13	22.8-30.5	45-70	26.3	61
13 Dec 97	17.9	177	33	15.9-34.1	22-78	27.2	60
13 Jan 98	18.9	148	35	16.1-34.2	26-69	26.0	55
11-Feb-98	19.5	48	23	17.7-29.9	29-74	22.8	47
12-Mar-98	21.0	310	35	18.4-42.1	29-109	31.0	69
14 Apr 98	19.0	87	29	19.2-39.3	28-94	30.6	67
12-May-98	26.1	85	24	25.5-41.4	51-98	32.3	74
Total		1019	254				

The Gompertz model appropriately described the juvenile white mullet growth (Fig. 3) (r^2 = 0.94, n = 254). The length increment was positive for the age interval analyzed. Based on estimates from the model, the average growth rate during the first 40 days was 0.24 mm d^{-1}, from 40 to 60 days it was 0.29 mm d^{-1}, from 60 to 80 days it was 0.32 mm d^{-1}, and during the last month in the lagoon was 0.35 mm d^{-1} (Table 2). The maximum growth rate would coincide with the time when the fish left the lagoon for the open coastal area.

DISCUSSION

The presence of juvenile white mullet *M. curema* in El Conchalito Lagoon come from the species behavior of moving to protected areas during the juvenile stage (Odum, 1972; Yáñez-Arancibia, 1976; Powles, 1981; Ferrer-Montaño, 1994; Ditty & Shaw, 1996). Using nets with different mesh size and a systematic sampling program assured us of sampling representative sizes of juvenile fish that enter the lagoon over time.

As a survival strategy, white mullet juveniles move into coastal lagoons to avoid potential predators in the adjacent coastal areas (Yáñez-Arancibia, 1976; Marin & Dodson, 2000). Their presence, represented by individuals from 16 to 42 mm SL, was also recorded in El Conchalito Lagoon during 1996 (González-Acosta *et al*., 1999), 1998 and 1999 (Quiñonez-Velázquez & Mendoza-Guevara, 2009). Outside the lagoon, in La Paz Bay, juvenile white mullet were 70-90 mm SL (Chávez, 1985). This suggests that those sized juveniles in the lagoon are a consistent pattern, and individuals < 50 mm SL will have greater possibilities of survival in the protected lagoon areas than outside in coastal areas, at least during that early life stage. White mullet has a wide spawning period with two peaks; one in winter and another in summer (Alvarez-Lajonchere, 1976; Marin *et al*., 2003; Traper *et al*., 2009), this has been evidenced using gonad maturity of adults and through the size structure of juvenile in coastal lagoons. The size structure of juvenile shows two cohorts with sizes between 20 to 50 mm SL (Marin *et al*., 2003; Traper *et al*., 2009), similar to the registered in the present study.

The movement of white mullet larvae from the sea toward estuaries and coastal lagoons should happen after metamorphosis (Yáñez-Arancibia, 1976; Marin & Dodson, 2000). Ditty & Shaw (1996) reported sizes of larval and juvenile white mullet from the north of the gulf of Mexico shelf, between 2-26 mm SL, and comment about the presence of white mullet eggs demonstrating the species spawns outside of the coastal lagoons. Accordingly to Anderson (1957), prejuveniles moving inshore at 17-25 mm SL, which is the smallest size recorded in El Conchalito Lagoon, during this study.

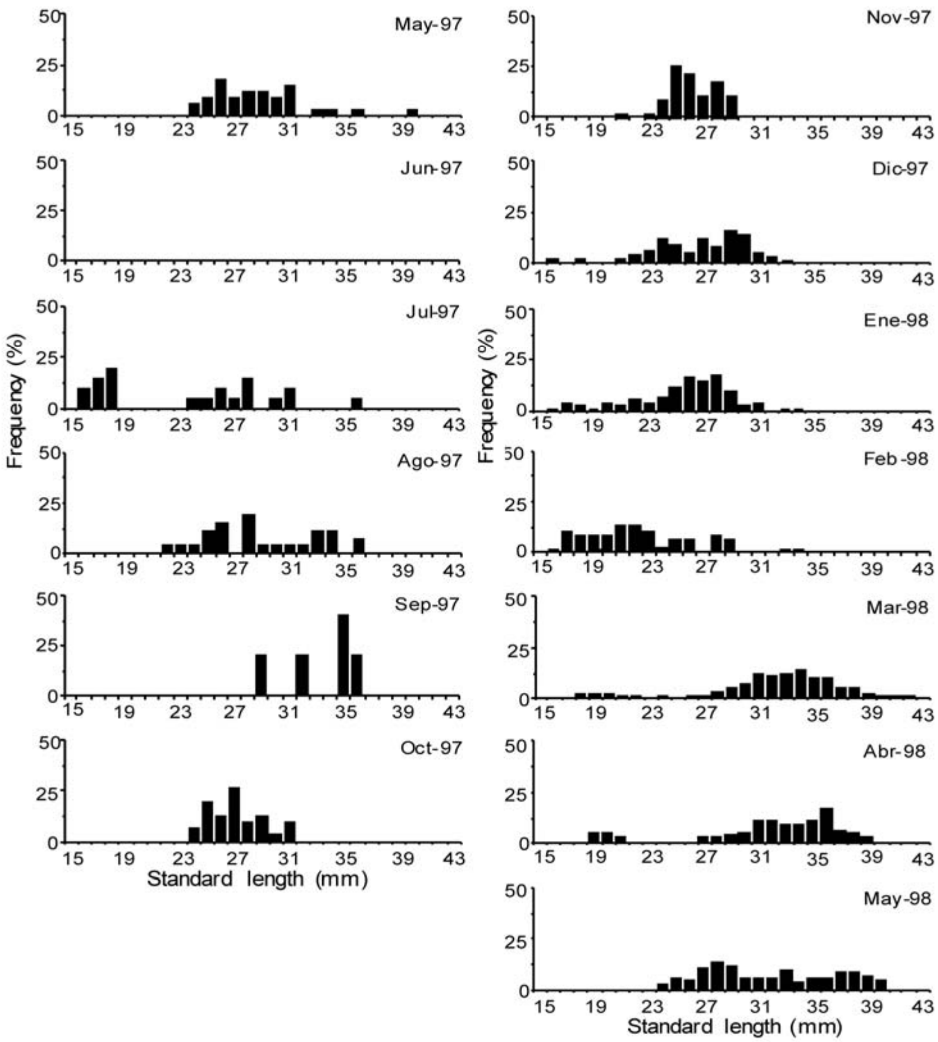

Figure 2. Monthly length frequency distribution of juvenile white mullet (*Mugil curema*) caught in El Conchalito Lagoon, May 1997 to May 1998.

Figura 2. Distribución mensual de la frecuencia de longitud de juveniles de lisa (*Mugil curema*) recolectados en la laguna El Conchalito, mayo 1997 a mayo 1998.

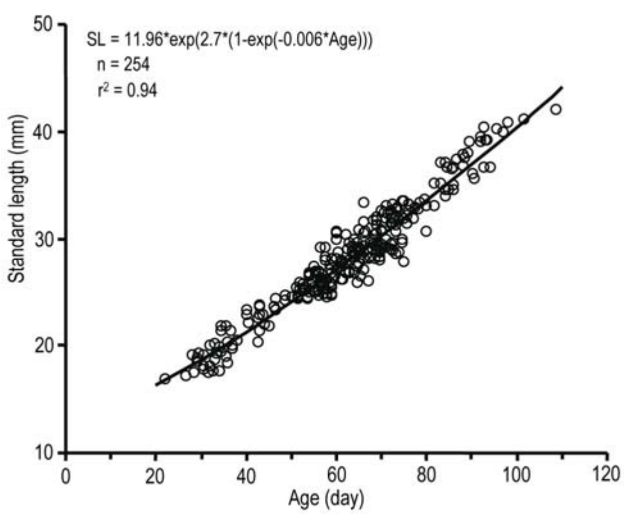

Figure 3. Age-SL data and fitting line of the Gompertz growth model of juvenile white mullet (*Mugil curema*), sampled in El Conchalito Lagoon, May 1997 to May 1998.

Figura 3. Datos de edad-LE y línea de ajuste del modelo de crecimiento de Gompertz de juveniles de lisa (*Mugil curema*) recolectados en la laguna El Conchalito, mayo 1997 a mayo 1998.

Table 2. Growth rate estimates (mm day^{-1}) for five days intervals of the juvenile white mullet (*Mugil curema*) sampled in El Conchalito Lagoon, May 1997 to May 1998.

Tabla 2. Estimaciones de la tasa de crecimiento (mm día^{-1}) por intervalo de cinco días de juveniles de lisa (*Mugil curema*), mayo 1997 a mayo 1998.

Age (days)	Growth rate (mm day^{-1})
0-5	0.20
5-10	0.21
10-15	0.22
15-20	0.23
20-25	0.24
25-30	0.25
30-35	0.26
35-40	0.27
40-45	0.28
45-50	0.28
50-55	0.29
55-60	0.30
60-65	0.31
65-70	0.32
70-75	0.33
75-80	0.33
80-85	0.34
85-90	0.35
90-95	0.35
95-100	0.36
100-105	0.36
105-110	0.37

White mullet showed a growth rate of 0.56 mm d^{-1} along the coasts of Florida (Martin & Drewry, 1978) higher than the growth rate reported here of 0.30 mm d^{-1}, and 0.26 mm d^{-1} reported by Marin (1996). The difference in growth rate may be because growth data from both larval and juvenile stages were used in the Florida study to describe the early development of the Mugilidae Family, and that larvae growth is more rapid before moving into the lagoon. This last can be evidenced from the lowest values of the average length-age in July-1997 (26 mm SL, 56 days old) and February-1998 (23 mm SL, 47 days old) in the present study (Table 1), resulting a growth rate of 0.47 mm d^{-1}, considering that those average lengths represent the time when juveniles were moving into the lagoon (Anderson, 1957). This suggests that growth is more rapid in the coastal zone than inside the lagoon, and the strategy of being moved to protected areas is to reach a length that maximizes escape from predation when they return to the coastal areas where the conditions for growth are better and probability of survival is maximized. The growth rate varies positively with survival (Shepherd & Cushing, 1980; Houde, 1987; Fortier & Quiñonez-Velázquez, 1998), the results suggest the larvae and early juvenile white mullet have greater growth rates in the coastal area, but they will also have greater risks of mortality. That risk will be decreased by their remaining, from age 30 to 100 days in protected lagoon areas despite a reduced growth rate there. This idea is reinforced by the results of Chávez (1985) who reported length frequencies of juvenile white mullet > 50 mm SL in La Paz Bay. The results suggest evaluation of the potential survival as a function of the growth rate in juvenile white mullet that show different growth trajectories.

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