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SURVIVAL OF JUVENILE WHITE MULLET *Mugil curema* (MUGILIDAE) IN A COASTAL LAGOON

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ABSTRACT. The hatching date frequency distribution (HDFD) of juvenile white mullet (*Mugil curema*) sampled at monthly intervals in the coastal lagoon Ensenada de La Paz, B.C.S., México from May 1997 to May 1998 was reconstructed for different age intervals and corrected for differences in the accumulated mortality. The ratio of the HDFD at a given age to the HDFD at an earlier age was used as an index of the relative survival of juveniles grouped into 14-day hatch-date cohorts. The results show that the white mullet spawns during the whole year in Bahía de La Paz, with the highest survival of larvae from October to February. Variations of the relative survival of the age groups were correlated significantly to the variations in growth. A fast growth resulted in high survival while a slow growth yielded low and high survival. The latter was observed when the juveniles used the lagoon after 40-days-old, indicating that the area is used mainly as a refuge. The return to the coastal area can explain the decrease of juveniles older than 80 days in the lagoon.

Keywords: Baja California Sur, *Mugil curema*, juveniles, otolith, hatch date frequency distribution.

Supervivencia de juveniles de la lisa *Mugil curema* (Mugilidae) en una laguna costera

RESUMEN. A partir de la edad calculada en días se reconstruyó la distribución de frecuencias de fechas de nacimiento (HDFD por sus siglas en Inglés) para diferentes intervalos de edad de juveniles de lisa (*Mugil curema*) recolectados a intervalos mensuales en la laguna costera Ensenada de La Paz, BCS (México), de mayo 1997 a mayo 1998. Las HDFD fueron corregidas por diferencias en la mortalidad acumulada. El cociente de la HDFD a una edad determinada entre la HDFD a una edad previa se utilizó como índice de supervivencia relativa de juveniles agrupados en cohortes de 14 días de fechas de nacimiento. Los resultados muestran que la lisa desova durante todo el año en la Bahía de La Paz, con la mayor supervivencia larval de octubre a febrero. Las variaciones de la supervivencia relativa de los grupos de edad se correlacionaron significativamente con las variaciones en el crecimiento. Un rápido crecimiento genera una elevada supervivencia y un lento crecimiento genera baja y/o alta supervivencia. Eso se observó cuando los juveniles permanecen en la laguna después de 40 días de edad, lo que sugiere que la zona se utiliza principalmente como un refugio. El regreso a la zona costera se relacionó con la disminución de juveniles mayores a 80 días de edad en la laguna.

Palabras clave: Baja California Sur, *Mugil curema*, juveniles, otolito, distribución de frecuencias de fechas de nacimiento.

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INTRODUCTION

The white mullet *Mugil curema* (Valenciennes, 1836) is distributed on both coasts of the American continent. In the Pacific it is found from Magdalena Bay on the western coast of the Baja California Peninsula and from the Gulf of California to Chile (Harrison, 1995). Reproduction takes place off the coast and the juvenile enter estuaries and coastal lagoons following turbid gradients (Blaber, 1987; Trape *et al*., 2009). Sometimes they enter rivers and coral reefs (Lozano-Cabo, 1978). Bays, coastal lagoons, inlets, and swamp areas are used by various species as refuge and nursery areas where the organisms remain for several months (Odum, 1972; Yánez-Arancibia, 1976; González-Acosta, 1998; Ross, 2003).

In Ensenada de La Paz, on the southwest coast of the Gulf of California (Fig. 1), the white mullet is a common species all year, showing a bimodal length distribution (González-Acosta, 1998) and suggesting two recruiting groups. Growth in this species is rapid, achieving 25-cm length in one year (Martin & Drewry, 1978). An important step in the study of fish larvae and juvenile growth and mortality was the discovery of daily growth increments in the otoliths (Pannella, 1971). The daily nature of the growth increments was confirmed for the first time by Brothers *et al*. (1976) in the northern anchovy (*Engraulis mordax*). The daily deposition of the growth increments have since been described for many fish species (Wild & Foreman, 1980; Brothers & McFarland, 1981; Campana & Neilson, 1985; Jones, 1986; Stevenson & Campana, 1992). Radtke (1984) validated the deposition of daily growth increments in otoliths of the striped mullet (*Mugil cephalus*) and we assume that this is also true for *Mugil curema*.

The analysis of the otolith microstructure has shown its utility in the determination of age, identification of periods of stress, assessing individual growth, and estimation of the birth date of fish larvae (Wright & Bailey, 1996). A great portion of the fish larvae cohort does not survive the first year (Gulland, 1965). In consequence, studies of the abundance variations in fish populations have

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concentrated on the first months of life (Campana, 1996; Quiñonez-Velázquez, 1997). The differences between individuals that survive up to different stages of their ontogenetic development can be identified through the birth date frequency distribution of the survivors; this allows to study the conditions associated with favorable periods of growth and survival (Yoklavich & Bailey, 1990).

The white mullet spawning season in Bahía de La Paz takes place during several months in spring-summer (Chávez, 1985). Because of this long spawning period, the larvae will be born under different environmental conditions (feeding and predation) that will influence the growth rate and the probability of survival. By using the age in days and the capture date it is possible to estimate the birth date of the larvae and surviving juveniles at different stages of development. Also, by knowing the biotic and abiotic conditions during hatching periods, we can characterize the most favorable periods for the larval survival (Methot, 1983).

The objective of this study is to identify the favorable periods for growth and survival of the white mullet (*Mugil curema*) larvae captured in El Conchalito inlet, located within Ensenada de La Paz, from May 1997 to May 1998, based on the juvenile hatch dates frequency distribution (HDFD).

MATERIAL AND METHODS

Juvenile white mullet (*Mugil curema*) were captured over 13 monthly samplings in El Conchalito inlet located at the southeast end of the Ensenada de La Paz (24°07’53” N and 110°21’00” W) (Fig. 1). Samplings were made from May 1997 to May 1998during the highest tide of the month. Overall, 1019 specimens were collected

In order to catch the greatest size interval 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 (6-mm mesh); and two seine nets, 15-m long, 1.5-m high with a central cod-end 2-m long (6- and 3-mm mesh).

During each sampling, water surface temperature and salinity were recorded using a Horiba U-10 portable analyzer.

Sampled fish were put on ice inside labeled polyethylene bags until transported to the laboratory where the white mullet were separated from the rest of the fish and preserved in 96% alcohol. Fish were identified at species level using a morphological key (Harrison, 1995; Trape *et al*., 2009). To assess a potential effect of alcohol on the juvenile size, a subsample was selected to measure their standard length (SL ± 0.01 mm) using an electronic vernier caliper, and were then preserved individually in 96% alcohol until the measurement of the whole fish sample.

From the total of juveniles sampled monthly a subsample was selected at random choosing up to three juveniles of each 0.5 mm SL interval. The otoliths (sagittae) of the selected fish were extracted for age determination. Both otoliths were mounted on the same glass slide using instant glue. For age determination, the right otolith was used. To make evident the growth increments in the otoliths (Fig. 2), we grinded them on the sagittal plane to the nucleus using paper of 0.2 to 12 µm grit size.

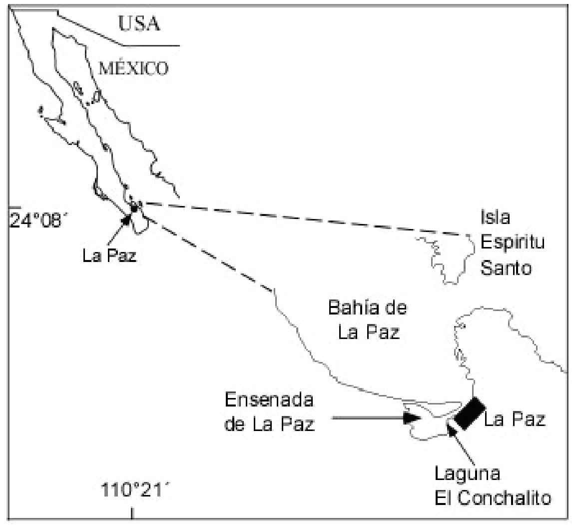

Figure 1. Location of study area. El Conchalito inlet is part of Ensenada de La Paz, which is in the southwest margin of the Gulf of California.

Growth increments were counted by two readers. The maximum error among readings was 6% and the average was used to assign the age (Suthers & Sundby, 1993). We assumed that the hatching mark is the first formed and the daily deposition growth increments according to Radtke (1984) for the striped mullet (*Mugil cephalus*). The same approach was used by Marín-Espinoza (1996).

With the purpose of transforming the size structure of juveniles in age structure, an age-length key per month was constructed. Thus, age was assigned to juveniles for which otoliths were not read.

The hatching dates of juvenile white mullet were obtained by subtracting the age from the date of capture. The juvenile fish hatched within 5-day intervals were grouped into cohorts and the absolute frequency for each cohort (number of juveniles) was calculated. The HDFD was constructed for all the juveniles and for age-group intervals of 20-40, 40-60, 60-80, and >80 days old.

The total mortality rate (Z) was estimated using the catch curve in linear form (Sparre & Venema, 1995) at constant time intervals (5 days), $LnC(t1,t2) = g - Zt$, where $LnC(t1,t2)$ = natural logarithm of the total catch (frequency of juveniles) in the age interval t1 to t2; g = constant and is the intercept to the origin of the regression line, Z = slope of the line and total mortality, and t = upper limit of the age interval.

This mortality rate was used for each 5-day cohort of the different age groups. For a given age interval, the over representation of late births in the HDFD was corrected by reduction of the 5-day cohort abundance in proportion to the average mortality that should have occurred during the time between the age average of the juvenile in the 5-day cohort and the upper limit of the age interval considered.

The survival of a 5-day cohort was defined as the change of the number of juveniles of the cohort of an age-group from the same cohort of the previous age-group (rate between the corrected frequencies). When the result was >1 (late incorporation to the lagoon), a 1 was assigned. To obtain an estimate of the cohort mortality, the value of survival was subtracted from one.

For the comparison between the growth and the mortality of the juvenile white mullet in Ensenada de La Paz, the hatch date intervals were extended to 14 days. The purpose of extending the interval was to reduce the empty periods in the distributions of the age groups of 20-40, 40-60, and 60-80 days.

RESULTS

The fresh length (range 16-34 mm SL) and length after the preservation in alcohol of 101 juveniles were compared to evaluate the effect of the alcohol during preservation. The potential effect was explored through the regression SLf =a+b*SLp, where SLp is the preserved length and SLf is the fresh length. The slope was 0.99 and is not significantly different from 1 ($P > 0.01$). In consequence, it was not necessary to correct the length after alcohol preservation.

The white mullet juveniles ranged from 16 to 42 mm SL and 22 to 109 days old (Table 1). The subsample of juveniles selected for age determination was 254 and are 25% of the total captured. The otolith microstructure showed opaque and hyaline zones and, according to Radtke (1984) these represent a daily growth increment (Fig. 2). The average water surface temperature ranged between 17.9 to 31.8 °C. Maximum temperature values coincided with the juvenile fish that had the longest lengths (29 to 37 mm SL) and greatest ages (67 to 90 days).

The monthly length-frequency distribution depicts two fish groups that show an increasing trend in average length (Fig. 3). The first group covers from May to September 1997 and the second one from October 1997 to May 1998. The average range of length of the fish in the groups are similar (KS-test, $P > 0.05$), 24-34 mm SL and 27-33 mm SL. The monthly age frequency distribution shows the same trend as the length frequency distribution, integrating two fish groups between 20 and 100 days of age (Fig. 4). The younger fish were observed in July 1997 and from December 1997 to April 1998, matching the smaller juvenile white mullet in the lagoon.

The juvenile hatch dates frequency distribution (HDFD), indicates that white mullet spawn throughout the year in Bahía de La Paz (Fig. 5). The maximum hatch frequency was detected in autumn-winter. In other periods frequencies were < 20 juveniles. A good relationship was observed between the HDFD and temperature (Fig. 5A) ($n = 11$, $P < 0.05$, Spearman-Correlation) and with tidal height (Fig. 5B) ($n = 26$, $P < 0.01$, Spearman-Correlation). These two variables showed an inverse seasonal

Table 1. Range and average of standard length and age of the white mullet (*Mugil curema*) captured in Laguna El Conchalito, May 1997 to May 1998.

Date	Temp	Juvenile		Range		Average	
	(°C)	Total	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				

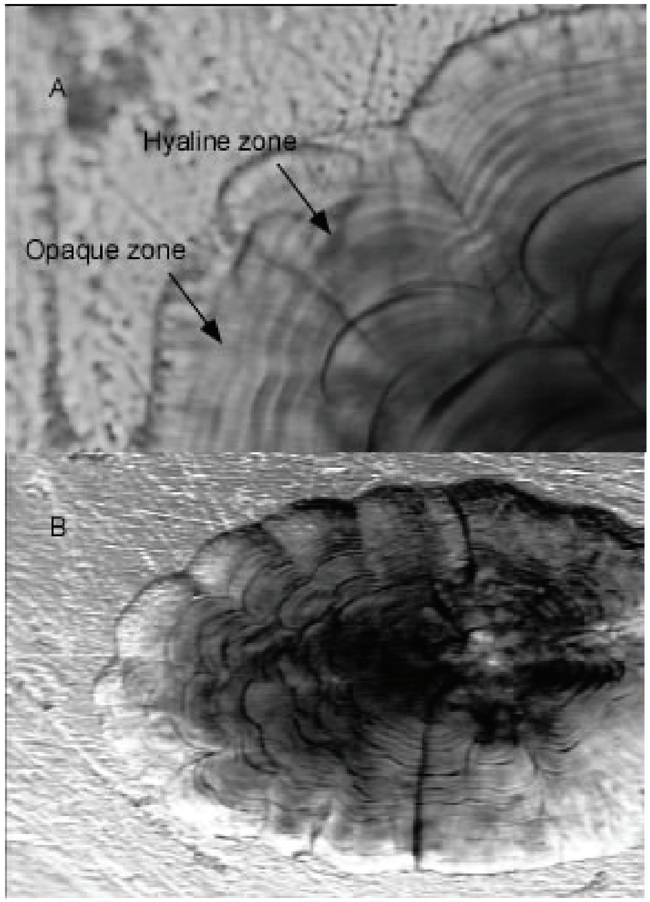

Figure 2. Microstructure of the right sagittae of a white mullet juvenile (*Mugil curema*) 22 mm SL and 45 days old, at 400X (a) and 200X (b) magnifications; with transmitted light.

pattern. When the temperature was at a minimum during December-January, the tidal height was at a maximum. During the same months, the HDFD also showed maxima. This HDFD includes the overrepresentation of juveniles that were born close to the sampling dates. These juveniles have been exposed to causes of mortality (changes in the food availability, predation) for a smaller period than juveniles born earlier. To reduce this effect of overrepresentation, we estimated a decreased rate (mortality) in relation to age (Fig. 6). The age structure of the total juvenile catch had a normal distribution ($P = 0.15$). To estimate the mortality rate, the decreasing part of the age distribution was used from 70 days being obtained a value of 0.04 for mortality at each 5-days interval.

The white mullet juveniles were divided into four age groups (20-40, 40-60, 60-80, >80 days) and their corrected HDFD was obtained (overrepresentation) (Fig. 7). The HDFD of juvenile age-group 20-40 days is different from the HDFD of juveniles 40-60 days. The latter age-group is similar to the HDFD of juvenile of 60-80 days. The HDFD of juveniles > 80 days is different from the previous age-groups and was little represented. These results suggest the mortality of the juvenile stabilizes after the juveniles were incorporated into the lagoon, on the average at an age of 30 days. The form of the HDFD of the juveniles > 80 days we infer is the result of the differential return of the juveniles to the coastal area and not caused by mortality.

Few juvenile fish survivors were born during spring-summer 1997 in all four age groups. This suggests that the survival conditions were more favorable during autumn 1997 and winter 1997-98 for these young juveniles. The juveniles from 40-60 days ($n = 233$) and 60-80 days ($n = 457$) had similar HDFD´s (representing the same 5-days cohorts). Also, this suggests juveniles of these ages were vulnerable to sampling during the year. In the age group > 80 days ($n = 236$), the hatch dates were the same as in the two previous age groups, but their small representation is the result of an asynchronous exit from the lagoon, to about 80 days. To explore the relationship between growth and mortality, the juveniles were regrouped into 14-day hatch intervals

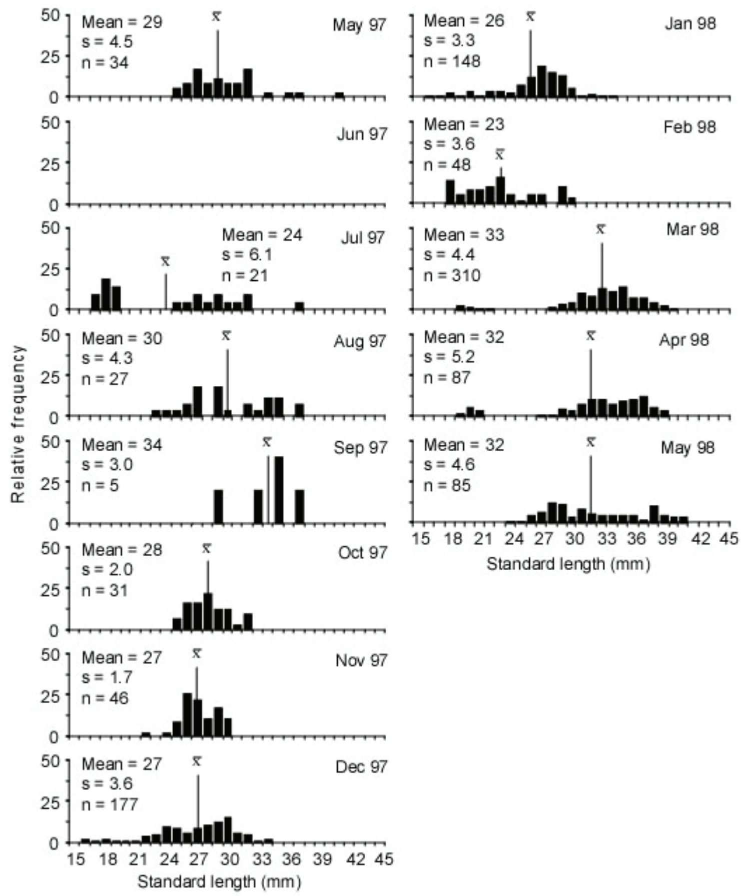

Figure 3. Monthly distribution of length frequency (%) of white mullet juvenile (*Mugil curema*) captured in Ensenada de La Paz, May 1997 to May 1998.

(Fig. 8). Two important events were noted. The first is a significant relationship between the growth rates and mortality ($r = 0.60$, $P < 0.05$). Juveniles with high growth rates had low mortality. The second is that the values to the left side of the broken line (> 40 days) correspond to the juveniles during their stay in the lagoon, mainly juvenile fish between 40 and 60 days old. These have a lower growth rate and low and high values of mortality. This suggests that the fish that enter the lagoon are those of rapid growth during their early life in the coastal zone (< 20 days) and a decrease in growth during their residency in the lagoon (after 40 days) with variable survival. This suggests white mullet juveniles use the lagoon mainly as a refuge area.

DISCUSSION

As a survival strategy, the white mullet enters estuaries and lagoons thus avoiding potential predators in the coastal area. The lengths best represented during the study in Ensenada de La Paz were 29-30 mm SL. However, in Bahía de La Paz the lengths best represented were 70-90 mm SL (Chávez, 1985). This suggests that the presence of juveniles <50 mm SL in the inlet is a consistent pattern and those juveniles will have greater possibilities of survival in protected areas such as lagoons than in the coastal zone. This was most evident for juveniles between 40 and 60 days of age by increasing survival during residence in the inlet, however episodes of high mortality are also present. Individuals >80 days (45-50 mm SL) were little represented in the lagoon because of having begun their return to the coastal zone. This is reinforced by the results of Chávez (1985) who recorded a minimum frequency of fish < 50 mm SL and a significant number > 50 mm SL.

The migration of *Mugil curema* towards the coastal area should happen after metamorphosis (Yánez-Arancibia, 1976; Marín-Espinoza, 1996). The structures of length and age analyzed suggest spawning occurs outside of the coastal zone, and juveniles recently metamorphosed require 20 to 40 days to enter Ensenada de La Paz. We assume white mullet juveniles, with ages between 40 and 80 days are permanent residents in the bay and show seasonal changes in abundance. Also, juveniles captured in El Conchalito inlet appropriately represent

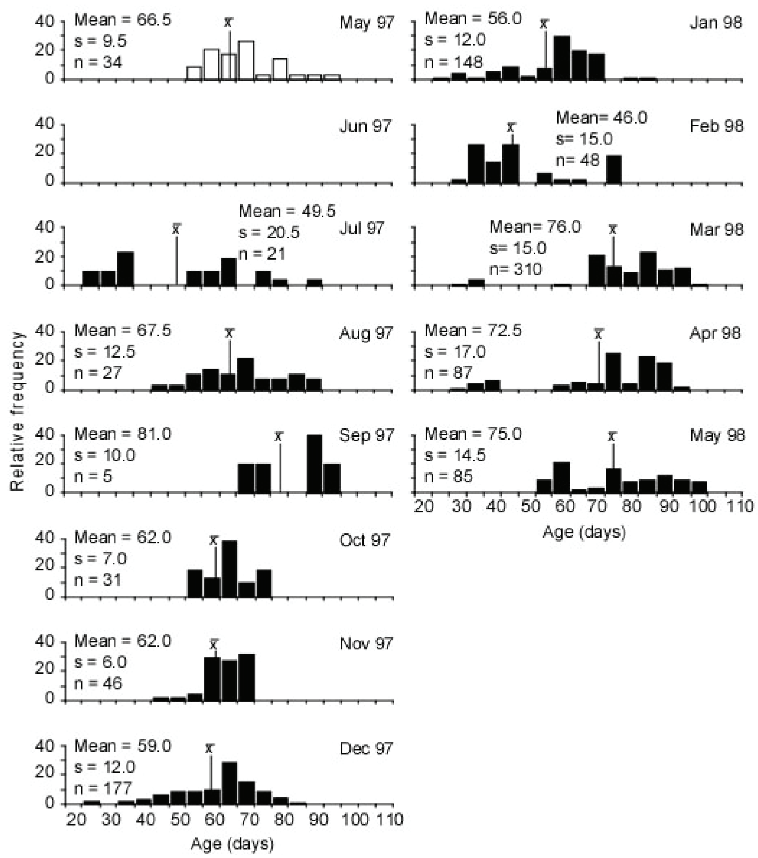

Figure 4. Monthly distribution of age frequencies (%) of white mullet juvenile (*Mugil curema*) captured in Ensenanda de La Paz, May 1997 to May 1998.

the fish group inside the bay. The smallest sizes of white mullet were captured in December 1997 and January 1998 and were in the 16 mm SL interval. Ditty and Shaw (1996) recorded for the north of the Gulf of Mexico shelf white mullet larvae and juvenile with lengths between 2-26 mm SL. We assume the white mullet juveniles move toward bays and lagoons after metamorphosis, [7.0 to 7.2 mm SL, Martin & Drewry, 1978] and on average they will take 30 days during which they will grow until reaching 16 mm SL. Ditty and Shaw (1996) also mention the presence of eggs of white mullet that demonstrates that the species spawns outside of the coastal zone.

The presence of defined groups of juveniles with 30 mm SL and 60 days on average during May-September 1997 and from October 1997 to May 1998 suggests the existence of two reproduction peaks per year, similar to that found along the coasts of Venezuela by Marín-Espinoza (1996).

In our work, the biggest catch of white mullet juveniles in Ensenada de La Paz was during autumn-winter. However, González-Acosta (1998) mentions that the abundance of white mullet juveniles < 50 mm SL decreases in winter. This difference could have been caused by the increase of the sea surface temperature from El Niño1997-98 with a potential increase in the development of eggs and yolk-sac larvae, because the temperature has a direct effect on the development time of the embryo and of the yolk-sac larvae (Ahlstrom & Moser, 1976). This potential increase in the development rate during the larval stage could increase survival, previous to metamorphosis, with an increase of the number of juveniles <60 days of age from December 1997 to April 1998. In this sense, Houde (1987) notes that an increase in the growth rate during the larval stage allows the larvae to avoid a larger number of potential planktonic predators, increasing survival because of a reduction of the time the larvae are available to predators. Another possible cause of the increase of juvenile survival in December 1997 to January 1998 is the presence of the highest tides during the year, increasing the volume of water flooding the lagoon and thus increasing the available habitat. The interannual differences of the winter tides define the recruitment of the white mullet in El Conchalito inlet. Victor (1983) recorded a positive relationship of the

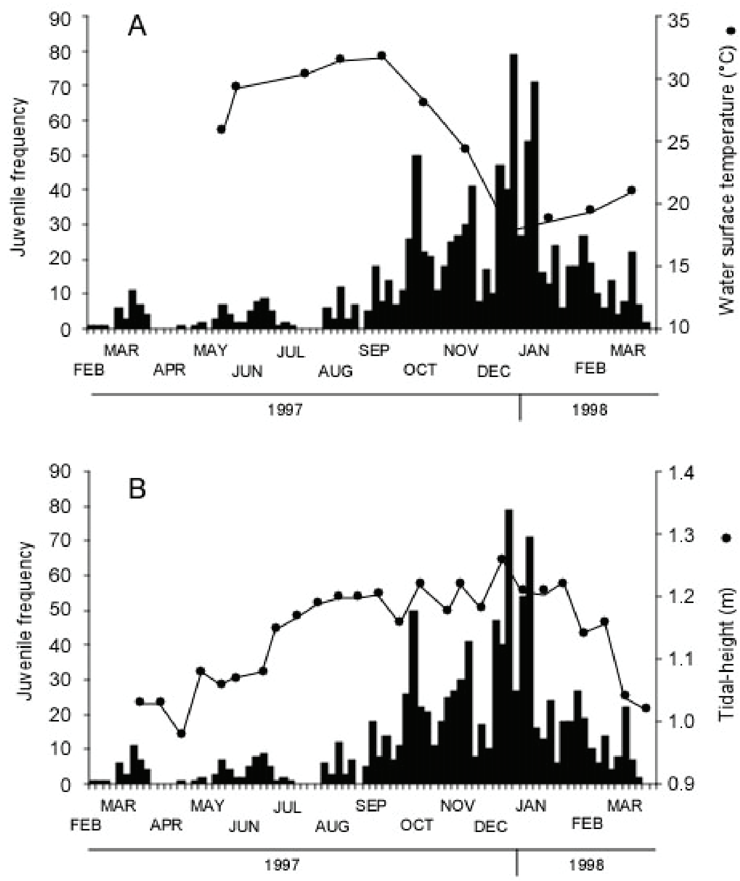

Figure 5. Hatch date frequency distribution of the white mullet (*Mugil curema*) captured in Ensenada de La Paz, May 1997 to May 1998, relationship to the seasonal change of the water surface temperature (A), and to the tide-height (B).

number of juveniles of *Thalassoma bifasciatum* entering the reef area at Isla San Blas, Panama with the periods of full moon. The biggest recruitment to the reef was during October-November 1980.

According to the above *M. curema* has a permanent presence of juveniles in Ensenada de La Paz (González-Acosta, 1998). Specifically, based on the HDFD, the spawning of white mullet in Bahía de La Paz occurs throughout the year. This is similar to that reported by Marín-Espinoza (1996) for the same species along the coasts of Venezuela. This author found the maximum hatching periods during December-March, coinciding with cool temperatures, as a consequence of a moderate upwelling event. In our work, the maximum HDFD also coincides with the lowest seasonal temperature and with maximum tidal height. Reproduction all year round in tropical species is common (Bond, 1979; Lagler *et al*., 1984) and the spawning of many species related to upwelling events has also been documented (Cury & Roy, 1989; Suthers & Sundby, 1993; Marín-Espinoza, 1996).

Turbidity of the water causes low intensity of light at shallow depths. This has been noted as an important ecological factor in the survival of fish that use estuaries and lagoons during their early life (Blaber & Blaber, 1980). Blaber (1987) noted, for the Africa coast, that to avoid predators mullets enter and leave the lagoons along the bottom, taking advantage of the tidal currents that increase water turbidity and reduce light penetration. Because Ensenada de La Paz is shallow, the action of tides associated with winds will create currents that generate much turbidity. In consequence, the entrance and exit of juvenile fish associates to the tidal pattern. This mechanism will maximize survival in winter when the highest tides occur increasing the flooded area and the available habitat.

In Ensenada de La Paz, turbidity of the water and variations in temperature are caused by tides. Tides are the most important factor in the hydrological dynamics of the inlet, allowing the formation of a specific habitat (González-Acosta, 1998). The turbidity during the ebb of the tide creates a refuge

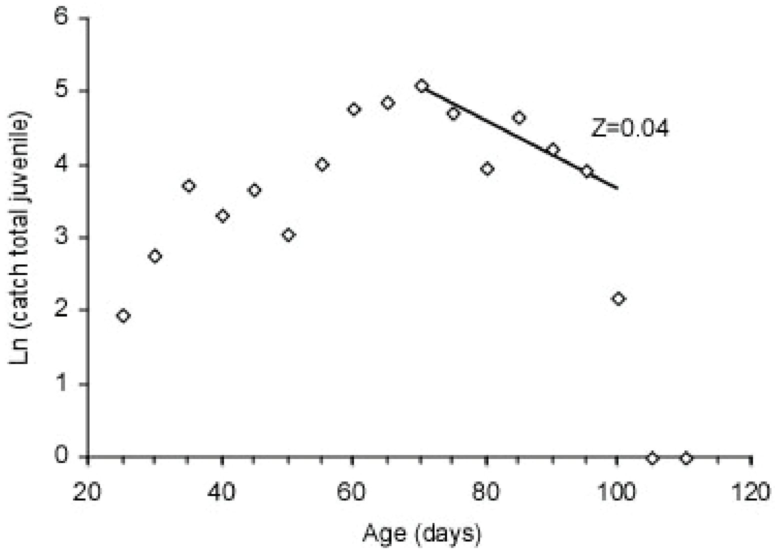

Figure 6. Age structure of the total number of white mullet juvenile (*Mugil curema*) captured in Ensenada de La Paz, May 997 to May 1998.

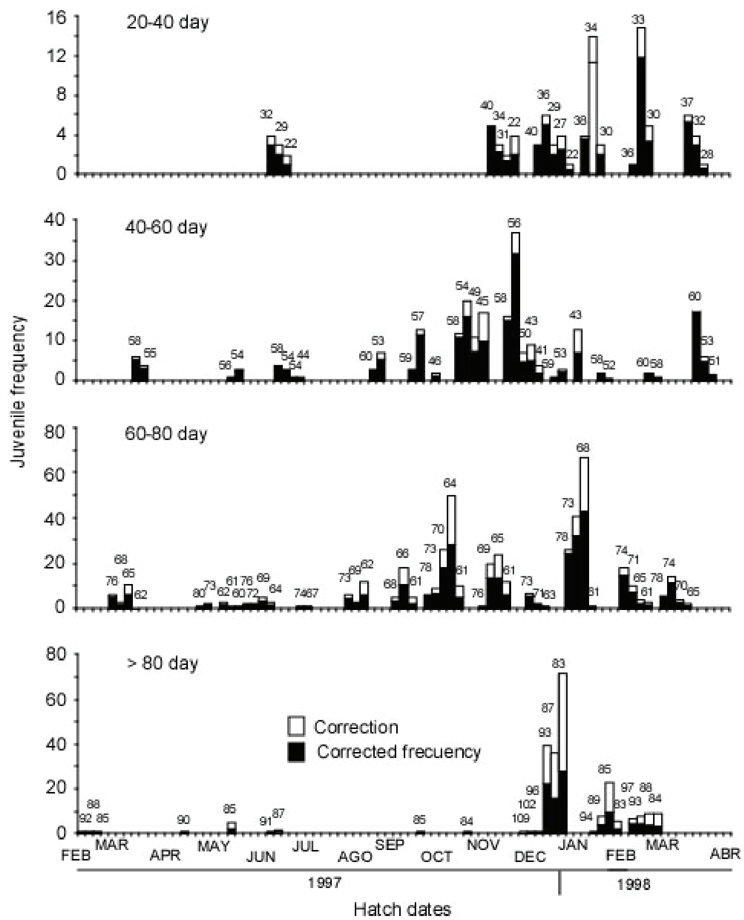

Figure 7. Correction for difference in the accumulated mortality for 5-day cohorts and for age groups. The sum of the empty and filled bars are the frequency without correction and the filled bar represents the corrected frequency. The values above the histograms are the age average for the cohort.

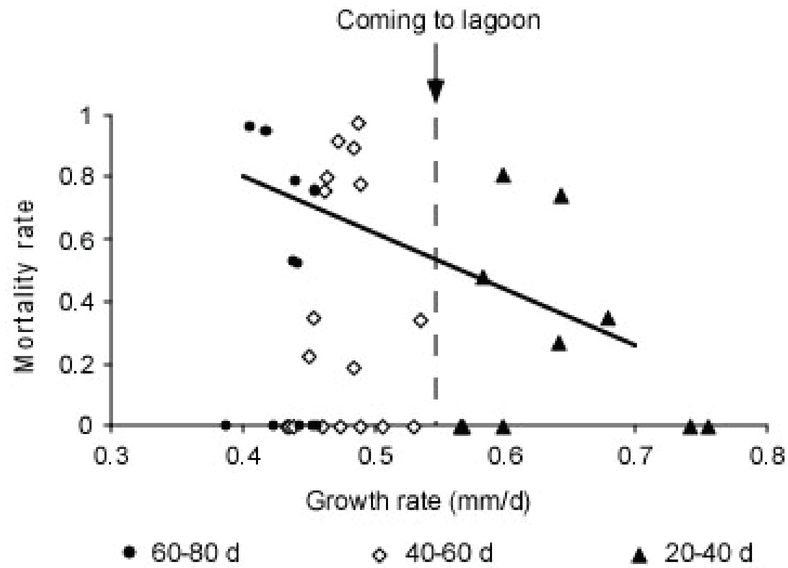

Figure 8. Relationship of the growth and mortality rates for age groups of the white mullet (Mugil curema) captured in Ensenada de La Paz, May 1997 to May 1998.

area against fish predation (Blaber & Blaber, 1980; Blaber, 1987), because predation is a function of the distance at which the prey will be detected visually and of predator size (Folkvord & Hunter, 1986). These conditions and the results of growth and survival in the present study suggest that Ensenada de La Paz is used mainly as a refuge by juvenile *Mugil curema* ranging from 20 to 80 day old.

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