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MARINE AND LAGOON RECRUITMENT OF *Litopenaeus vannamei* (BOONE, 1931) (DECAPODA: PENAEIDAE) IN THE "CABEZA DE TORO-LA JOYA BUENAVISTA" LAGOON SYSTEM, CHIAPAS, MEXICO

Cervantes-Hernández, P.[1], M. A. Gómez-Ponce [2] & P. Torres-Hernández[1]

[1]Instituto de Recursos e Industrias, Universidad del Mar, Ciudad Universitaria s/n, Puerto Ángel, Oaxaca 70902, México. [2]Unidad de Servicio "El Carmen", Instituto de Ciencias del Mar y Limnología. Universidad Nacional Autónoma de México. Ciudad del Carmen, Campeche 24157, México. email: pch@angel.umar.mx

ABSTRACT. Life cycle of the Penaeidae shrimp family is approximately 16 months and this takes place between the marine and coastal lagoon environments. Within the "Cabeza de Toro-La Joya Buenavista" lagoon system (CJB-LS) a total length value for 6116 juvenile white shrimp was recorded. Bhattacharya's method and modal progression analysis were used in order to analyze marine (MR) and lagoon (LR) recruitment periods. The MR is the natural movement of juvenile shrimp from the interior of CJB-LS towards the marine fishing zone (MFZ) from Gulf of Tehuantepec. The LR is the natural movement of shrimp post-larvae from the MFZ towards the interior of CJB-LS. Both recruitments were separated between September and October. The MR period was delimited from April 2001 to the middle of October 2001 (during rainy season). In this period, the age at which white shrimp began to migrate towards the MFZ was recorded between 4.5 and five months old. The LR period began during the last days of October 2001 and ended in March 2002 (during "Tehuanos" season). Only in this period were shrimp cohorts observed with an approximate age of 25 days. Those shrimp cohorts were considered as recently recruited, because they continued growing after their immigration from MFZ. Reproduction period of white shrimp occurs in the MFZ from July to November with maxima in October.

Key words: shrimp, recruitment age, coastal lagoons, Gulf of Tehuantepec.

RECLUTAMIENTO MARINO Y LAGUNAR DE *Litopenaeus vannamei* (BOONE, 1931) (DECAPODA: PENAEIDAE) EN EL SISTEMA LAGUNAR "CABEZA DE TORO - LA JOYA BUENAVISTA" CHIAPAS, MÉXICO.

RESUMEN. El ciclo de vida de los camarones de la Familia Penaeidae es de aproximadamente 16 meses y se desarrolla entre los ambientes marino y lagunar. En el sistema lagunar "Cabeza de Toro-La Joya de Buenavista" (CJB-SL), fue registrado el valor de la longitud total de 6116 juveniles de camarón blanco. El método de Bhattacharya y el análisis de progresión modal fueron usados para analizar los periodos de reclutamiento marino (RM) y lagunar (RL). El RM, es el movimiento natural de camarones juveniles desde el interior del CJB-SL hacia la zona marina de pesca (ZMP) del Golfo de Tehuantepec. El RL, es el movimiento natural de post-larvas de camarón desde la ZMP hacia el interior del CJB-SL. Ambos periodos de reclutamiento pudieron ser separados entre septiembre y octubre. El periodo del RM fue delimitado de abril 2001 hasta la mitad de octubre 2001 (durante la estación de lluvias). En este periodo, la edad a la cual los juveniles comenzaron a emigrar hacia la ZMP fue registrada entre 4.5 y cinco meses. El periodo del RL comenzó durante los últimos días de octubre 2001 y finalizó en marzo de 2002 (durante la estación de "Tehuanos"), sólo en este período fueron observadas cohortes de camarón con una edad aproximada de 25 días. Estas cohortes de camarón fueron consideraras como recién reclutadas porque éstas continuaron creciendo después de su inmigración desde la ZMP. El periodo de reproducción del camarón blanco ocurre en la ZMP de julio a noviembre con máximos en octubre.

Palabras clave: camarón, edad de reclutamiento, laguna costera, Golfo de Tehuantepec.

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INTRODUCTION

In the Gulf of Tehuantepec (GT) the white shrimp *Litopenaeus vannamei* (Boone, 1931) is captured in a marine area called fishing zone 90, which is located between Punta Chipehua near Salina Cruz, Oaxaca (16º01´31.39´´ N and 95º22´24.56´´ W) and Puerto Chiapas, Chiapas (14º40´55.81´´ N and 92º23´44.13´´ W) (Reyna-Cabrera & Ramos-Cruz, 1998) (Cervantes-Hernández, 2008) (Fig. 1). The marine fishing zone 90 has a total area of 8085 km^2 of continental platform and it is composed of five subsectors (Reyna-Cabrera & Ramos-Cruz, 1998). In the marine fishing zone 90, the ships operate from five to 40 fathoms (i.e., 9.1 to 72.8 m) using trawl nets with a mesh opening of 57.15 mm (INP, 2004). Throughout the GT, six lagoon systems are located along its coastline, but the most important (due to its shrimp production) are lagoon systems "Huave" in Oaxaca and "Mar Muerto" shared by the states of Oaxaca and Chiapas (Cervantes-Hernández, 2008) (Fig. 1).

The complete life cycle of the Penaeidae shrimp family is approximately between 15 and 18 months (Cervantes-Hernández, 2008). The life cycle begins in the marine environment with the reproduction process that generates larvae shrimp. After post-larvae shrimp enter lagoon systems for their protection, they feed and grow

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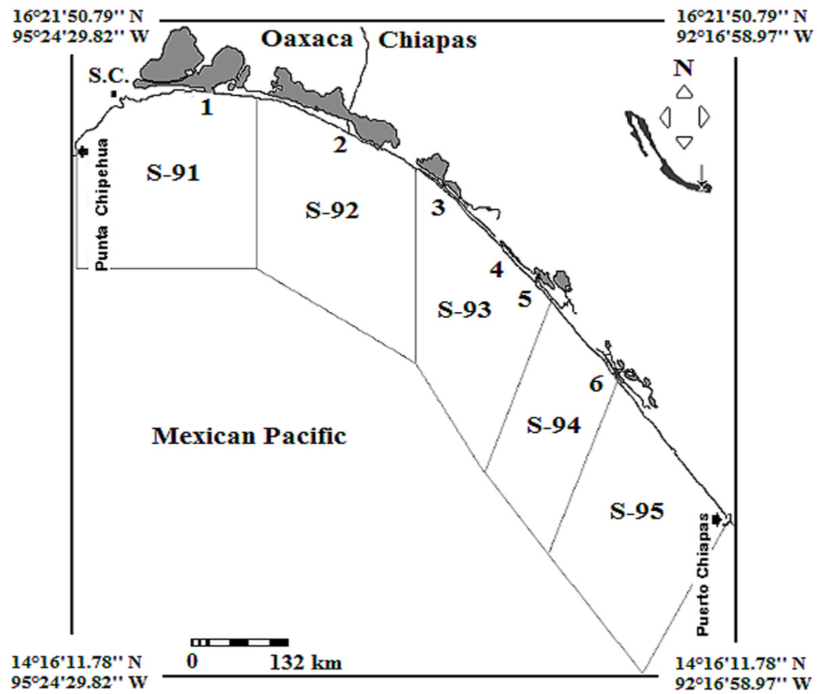

Figure 1. Geographic location of marine fishing zone 90 in the Gulf of Tehuantepec; sub-sectors (from S-91 to S-95); lagoon systems are: (1) "Huave"; (2) "Mar Muerto"; (3) "Cabeza de Toro-La Joya-Buenavista"; (4) "Patos-Solo Dios"; (5) "Carretas-Pereyra"; (6) "Chantuto-Panzacola"; (S.C.) Salina Cruz City.

until they reach the juvenile stage (Gracia *et al.,* 1997). Ricker (1975) indicated that recruitment is a process whereby organisms become potentially vulnerable to fishing mainly due to body length changes. These changes are biologically important because they activate emigration and immigration movements between different aquatic environments.

Cervantes-Hernández (2008) analyzed marine shrimp catches obtained in the marine fishing zone 90 between 1989 and 1998. Based on this information a fishery model was made to estimate marine and lagoon recruitment periods of *Farfantepenaeus californiensis* (Holmes, 1900). In this work the author defined the Marine Recruitment as the natural movement of juvenile shrimp from the interior lagoon systems towards the marine fishing zone 90 (Fig. 1). The author denominated recruits juvenile shrimp that were recorded at four and five months old. These ages were recorded with maximum abundance during: 1989-08, 1990-08, 1991-07, 1992-05, 1993-08, 1994-07, 1995-04, 1996-07 and 1997-09. The Lagoon Recruitment was defined as the natural movement of larvae shrimp from the marine fishing zone 90 towards the interior lagoon systems (Fig. 1). Although this author did not directly record larvae shrimp, his fishery model showed that when massive reproduction periods of *F. californiensis* occur in the marine fishing zone 90, larvae shrimp must increase, activating then lagoon recruitment period. The author associated massive reproduction periods with maximum abundance of shrimp spawners close to and at sexual maturity age (between six/seven and 16 months). These ages were recorded during 1989-11, 1990-12, 1991-10, 1992-08, 1993-12, 1994-10, 1996-10, 1996-01 and 1997-01.

The results obtained by Cervantes-Hernández (2008), were used by Cervantes-Hernández *et al.* (2008 a) to demonstrate, that the marine closure system implemented from 1993 in the GT (from March/April to September) (NOM, 1993; 2002) has not functioned adequately. The main problems that these authors detected in this marine closure system were excessive protection of the juvenile and prolonged exploitation period of spawners of *F. californiensis* and *L. vannamei.* Based on these results, the authors suggested that the old marine closure system should be changed from July to October to protect both recruitment periods.

The results published by Cervantes-Hernández *et al.* (2008 a) were not accepted by the fishery community in Oaxaca because the author did not include lagoon recruitment information in his fishery model. Nevertheless, this type of information had not been generated. For this reason, in this work marine and lagoon recruitment periods were analyzed in the

"Cabeza de Toro - La Joya-Buenavista" lagoon system (CJB-LS) from GT.

The results obtained in this work were compared with the results reported by Cervantes-Hernández (2008) to determine if both recruitment periods are consistent for *L. californiensis* and *L. vannamei.* Conclusions from this work will serve to support the proposal of changing the old marine closure system in the GT. Important fishery arguments were obtained through this work to understand how both recruitment periods develop between the CJB-LS and the marine fishing zone 90.

MATERIALS AND METHODS

Sampling

Every fifteen days between 2001-04-24 and 2002-03-28 at ten stations distributed randomly within the CJB-LS (Fig. 2), juvenile of *L. vannamei* samples were collected during morning between 08:00:00 and 10:00:00 using artisanal ships and atarraya nets with mesh opening of 0.9 cm. This period was chosen in order to widely cover recruitment and reproduction periods. A digital electronic vernier calliper (± 0.1 mm) was used to measure shrimp total length (L_T in mm) from the rostrum tip to the telson end. Juvenile of *L. vannamei* were identified, using the taxonomic keys of Hendrickx (1995). Fieldwork was done by technical personnel from the "Centro Regional de Investigación Pesquera" (CRIP-SC) from Salina Cruz, Oaxaca, México. Information generated by CRIP-SC was analyzed at the Universidad del Mar, Puerto Ángel, Oaxaca, Mexico, under project 2IR1104.

Cohort's analysis

Bhattacharya's method described by Goonetilleke and Sivasubramaniam (1987) was used in order to identify and separate shrimp cohorts in each analyzed fortnight. In this graphical method, the natural logarithm of abundance (N_t) must be estimated and its difference between successive abundances ΔLn (N_t) is plotted against L_T values. In this plot a shrimp cohort can be identified as a ΔLn (N_t) vs. L_T values group linearly ordered and separated from other cohorts using a negative lineal model. This negative lineal model is:

$$\Delta \mathrm{Ln}\ (N_t) = a - b \cdot L_T \qquad (1)$$

According to Malcolm (2001), the parameters a and b of the function (1) were estimated using the minimum likelihood of log-normal distribution (-Ln (a, b / N_t, L_T)), this is:

$$-\mathrm{Ln}(a, b/N_t, L_T)=\mathrm{sum}(\mathrm{Ln}(SD_\varepsilon)+(\mathrm{Ln}(2\pi)/2)+(\varepsilon^2/(2\cdot SD_\varepsilon)) \qquad (2)$$

Where: ε is the error structure or residual value of ΔLn (N_t), SD_ε is the standard deviation of ε estimated with SD_ε = root ((1 / n) · sum

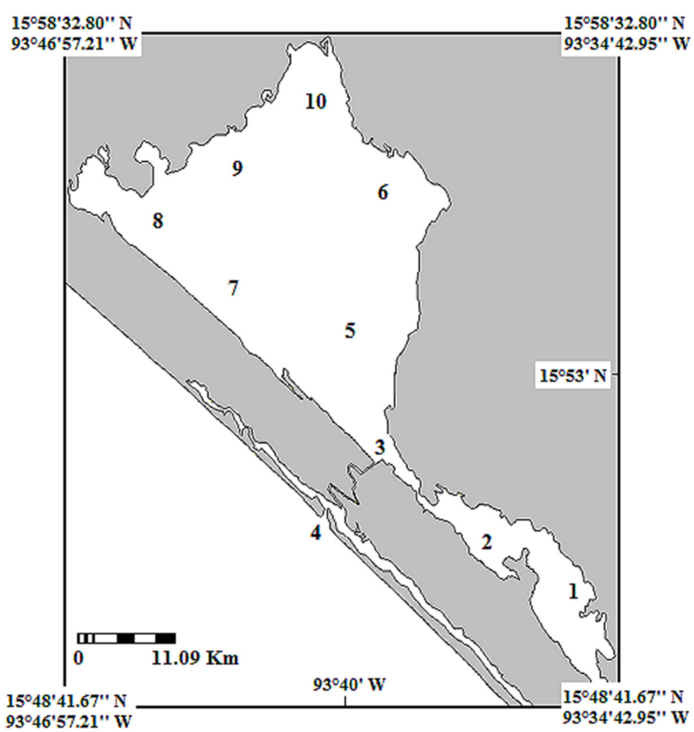

Figure 2. Geographic location of sampling station (from 1 to 10) in the Cabeza de Toro-La Joya-Buenavista lagoon system.

($\mathcal{E}^2$)), n are total records of L_T of each analyzed fortnight.

When parameters a and b were estimated for each shrimp cohort, the mean length (L_M) was calculated using:

$$L_M = a/b \qquad (3)$$

Bhattacharya's method was performed using the computer software BOBP/MAG/4. The function (2) was resolved using computer software Analysis Matrix Population (Pop-Tools) and with support "Solver" an Excel tool. Solver was used with a precision at 0.000001 combined tangent, progressive and Newton algorithms.

To develop minimum likelihood method it was necessary to define error structure and, in this work, the $\mathcal{E}$ had a log-normal distribution. Malcolm (2001) indicated that the distribution of catches is often log-normally distributed in fisheries models.

Modal progression analysis and age estimation

Shrimp cohorts and their L_M values were ordered on an ascendant criterium fortnight by fortnight to build a new plot using time as X-axis and L_M as Y-axis. This plot was used to develop a modal progression analysis according to Sparre and Venema (1995). In this analysis type, a modal progression line must be diagonally drawn between a minimum value and a maximum value of L_M. Once this is done, modal progression trajectory line can be diagonally followed to see how L_M values increase between fortnights until they reach the maximum value of L_M.

To assign an approximate age to each L_M value, the criterium reported by Chávez (1979) was used. This author obtained L_M records for *L. vannamei* in "Huave" lagoon system (Fig. 1) and, based on these records, the author indicated that when these organisms have reached between 48 and 55 mm, they are juvenile shrimp with an approximate age of one month. Organisms with a L_M value between 42 and 47 mm are recently recruited younger shrimp with an approximate age of 25 days.

In this work all shrimp cohorts that began with a L_M value between 48 and 55 mm were assigned with an age of one month. Then, following the modal progression trajectory line diagonally, fifteen more days were added to know the approximate age of the next shrimp cohort. This additive process continued fortnight by fortnight until reaching the maximum value of L_M in each modal progression lines obtained. When the modal progression lines did not begin with aforementioned L_M values (less or greater), the additive process was the same. The approximate age of the next shrimp cohort was thus estimated using the minimum value of L_M recorded in these modal progression lines.

Recruitment analysis

To analyze marine and lagoon recruitment periods in the CJB-LS, sampling times (between 2001-04-24 and 2002-03-28) were separated into two periods on the aforementioned plot. These periods were the same as those used by Cervantes-Hernández (2008) to describe marine and lagoon recruitment periods in the marine fishing zone 90. According to this author, the first period represented marine recruitment and was delimited from April to October (during rainy season). The second period represented lagoon recruitment and was delimited between the last days of October and June (during "Tehuanos" season).

Two additional criteria were considered to explain how marine and lagoon recruitment could develop between the CJB-LS and the marine fishing zone 90. a) when a shrimp cohort reached the maximum L_M value in a modal progression line, this line would continue growing within the CJB-LS, but the next shrimp cohort would not be able to be observed inside the lagoon system, because it migrated toward the marine fishing zone 90, then marine recruitment had begun; and b) when a shrimp cohort began to grow in a modal progression line and this shrimp cohort was recorded with a L_M value between 42 y 47 mm, then the shrimp cohort was considered as recently recruited, because they continued growing after their immigration from the marine fishing zone 90 towards the interior CJB-LS. The presence of younger shrimp within the CJB-LS suggests that lagoon recruitment had begun.

RESULTS

Cohort's analysis

During sampling times 6116 readings of L_T were done. Figure 3 shows each analyzed fortnight and the L_M values estimated for each shrimp cohort.

With 23 fortnights sampled, 200 shrimp cohorts were identified and separated (Fig. 3). A higher number of shrimp cohorts were observed during June, July and October fortnights. Fewer shrimp cohorts were recorded from January to March (Fig. 3).

Modal progression analysis and age estimation

Marine and lagoon recruitment could clearly be separated into two periods and the separa-

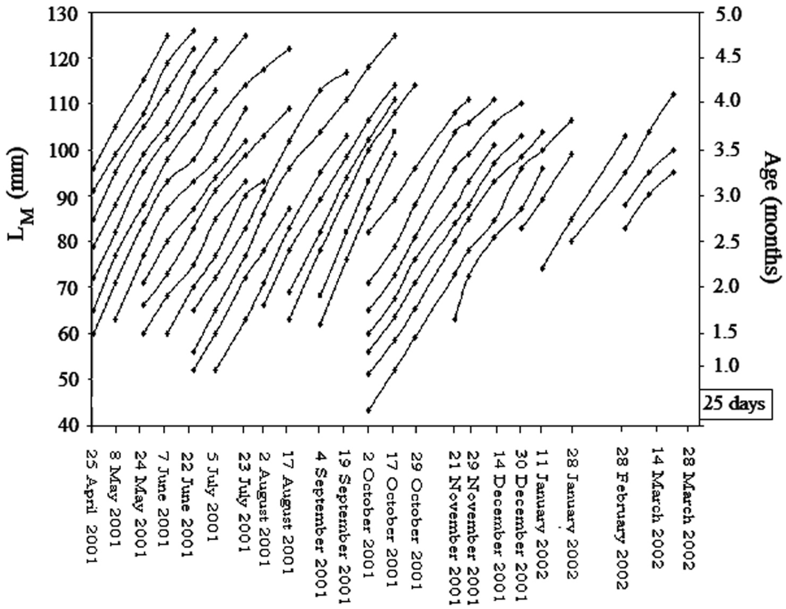

Figure 3. Modal progression analysis for *L. vannamei* in the CJB-LS between 2001-04-24 and 2002-03-28. Points are shrimp cohorts and lines that connect points are the modal progression lines.

tion point between these periods was observed between September and October (Fig. 3). The first period was delimited from April 2001 to mid October 2001 (during rainy season) and 21 modal progression lines were recorded (Fig. 3). The second period began during the last days of October 2001 and ended in March 2002 (during "Tehuanos" season) and 13 modal progression lines were recorded (Fig. 3).

In the first period, the modal progression lines began to grow with L_M values greater than 52 mm at an approximate age between one and 1.5 months old (Fig. 3). In these modal progression lines, shrimp cohorts reached the maximum L_M values between 120 and 125 mm at an approximate age between 4.5 and 4.8 months old (Fig. 3). This means that a higher shrimp cohort number at an approximated age of five months old began to emigrate from the interior the CJB-LS towards the marine fishing zone 90 (Fig. 3). In this period, shrimp cohorts with L_M values between 42 and 47 mm were not observed (Fig. 3).

In the second period, the modal progression lines began to grow with L_M values between 42 (with an approximate age of 25 days old) and 52 mm (with an approximate age of one month old) (Fig. 3). In these modal progression lines shrimp cohorts reached maximum L_M values between 105 and 110 mm at an approximate age between 3.7 and four months old (Fig. 3). Fewer shrimp cohorts were observed beginning to emigrate from the interior the CJB-LS towards the marine fishing zone 90 (Fig. 3), but a greater number of shrimp cohorts were observed beginning to immigrate from the marine fishing zone 90 towards the interior the CJB-LS (Fig. 3).

Recruitment analysis

The results obtained suggest that in the CJB-LS marine recruitment continues throughout collected time, but it was higher during the first period, especially in June and July 2001. Lagoon recruitment also continues throughout collected time, but it was higher during the second period, especially in the last days of October 2001(Fig. 3).

The age at which *L. vannamei* began to emigrate towards the marine fishing zone 90 was recorded between 4.5 and five months old (Fig. 3). We named these ages "recruitment age".

DISCUSSION

Knowledge of the annual abundance variation of recruits and spawners is critical to the management of all fisheries (Penn & Caputi, 1986). For an organism whose age cannot be accurately estimated (such as penaeid shrimp), the length-cohort models can identify recruitment and spawning periods in natural populations (Watson *et al.*, 1996).

The INP (2004) described the massive egg-laying periods of mature female brown shrimp in phase IV in the GT between 1982 and 2002. Phase IV in the shrimp of the genus *Penaeus* is characterized by dark colored mature ovaries and an empty gonadal mass (Sandoval-Quintero & Gracia, 1998). The INP (2004) reported a higher percentage of mature female brown shrimp in phase IV from October to January. In these same months Cervantes-Hernández (2008) predicted lagoon recruitment period for *F. californiensis* and, during this period, the author reported an increase in the spawners number of this shrimp. In the CJB-LS, 25 day old white shrimp cohorts were observed only during October 2001. Those shrimp cohorts were considered as recently recruited, because they continued growing after their migration from the marine fishing zone 90.

During "Tehuanos" seasons the presence of very young shrimp suggests a flow of post-larvae shrimp from the marine fishing zone 90 towards the interior of the CJB-LS. This flow of post-larvae shrimp can be explained by a reproduction period in open sea and, according to Cervantes-Hernández *et al*. (2008 b), this period was recorded from July to November with maxima in October. During this period, a greater post-larvae shrimp number can be observed in the marine fishing zone 90 because food is more readily available (phytoplankton and zooplankton), according to high levels of chlorophyll a detected in the GT and INP (2004), because mature female brown shrimp in phase IV are dominant.

Cervantes-Hernández *et al*. (2008 b) described some oceanographic conditions of the GT between 1989 and 1998. On average, chlorophyll a concentration was lower during marine recruitment in the rainy season (0.13 mg m-3) and greater during lagoon recruitment in the "Tehuanos" season (0.42-1.10 mg m-3). These authors proposed that between October and January (when the maximum abundance of spawners and the higher percentage of egg-laying of mature females in phase IV occurred), larval survival was greater because food was more available. On the other hand, from July to August/September (when the maximum abundance of recruits and the lower percentage of egg-laying of mature females in phase IV occurred), larval survival was lower because food availability diminished according to the low levels of chlorophyll a observed in the GT.

On the other hand, the INP (2004) reported a smaller percentage of mature female brown shrimp in phase IV from July to September. In these same months Cervantes-Hernández (2008) predicted marine recruitment period for *F. californiensis* and, during this period, the author reported an increase in the juvenile number of this species. For *L. vannamei* from the CJB-LS, a higher number of white shrimp cohorts between 4.5 and five months of age were observed within the CJB-LS, especially during June and July. This fact was interpreted as evidence that those shrimp cohorts began to migrate towards the marine fishing zone 90.

During the rainy season along the coastline between the states of Oaxaca and Chiapas, higher levels of pluvial precipitation were recorded between June and September 2001 (337-397 mm). During the "Tehuanos" season lower levels of pluvial precipitation were recorded from October to April (20-30 mm) (SMN, 2008). Several authors have reported a direct relationship between shrimp abundance and pluvial precipitation (Ruello, 1973; García & Le Reste, 1986; Cervantes-Hernández, 1999). These authors indicated that pluvial precipitation together with fluvial unloading in lagoon systems stimulate the emigration of juvenile shrimp due to diminishing salinity (chemical stimulus). Another associated factor is an increase of the water turbidity which diminishes the natural mortality rate due to depredation when shrimp leave lagoon systems.

Our results indicate that between the CJB-LS and the marine fishing zone 90, marine recruitment period for *L. vannamei* was delimited from April 2001 to mid October 2001 and recruitment in lagoons began during the last days of October 2001 and ended in March 2002. These conclusions were consistent with marine and lagoon recruitment periods predicted for *F. californiensis* in the marine fishing zone 90 by Cervantes-Hernández (2008), who reported a recruitment age for *F. californiensis* of five months. In the CJB-LS the recruitment age for *L. vannamei* was estimated between 4.5 and five months.

The results obtained in this work show that the fishery model development by Cervantes-Hernández *et al.* (2008 a) generated correct conclusions to demonstrate that the old marine closure system in the GT has not functioned adequately. The main problems detected in this marine closure system were excessive protection of the juvenile and long exploitation period of spawners of *F. californiensis* and *L. vannamei.* For this reason, we suggest that the old marine closure system should be changed from July to October to protect both recruitment periods. For details on marine closures system changes, see Cervantes-Hernández *et al.* (2008 a).

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