

Recruitment Age of *Litopenaeus vannamei* (Boone, 1931) (Decapoda: Penaeidae) in the Cabeza De Toro-La Joya Buenavista Lagoon System, Oaxaca-Chiapas, Mexico

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Abstract

At present, the fishery of *Litopenaeus vannamei* continues overexploited in the Gulf of Tehuantepec (GT), Mexico. From the available literature it was demonstrated that marine closure systems implemented in GT have not worked adequately since 1993, because these are completely protecting marine recruitment seasons, and reproductive seasons were only partially considered to protect. Due to these problems, new marine closure systems were proposed in the literature, but they were not accepted by fishermen from GT because they did not include marine and lagoon recruitment information. For this reason, in this study both recruitment types were analyzed with estimations on the recruitment age (*RA*), and its relationship with total length and weight. To the Cabeza de Toro la Joya Buenavista lagoon system (CTJB-LS), it was concluded that young recruits migration toward outside CTJB-LS elapsed between 3 and 5-m-olds, with the highest recruit flow in 4-m-olds. Thus, this last age was called the *RA* of *L. vannamei* (at 106 mm). Maximum marine recruitment ranked from June to July, and maximum reproductive seasons were in October. In both recruitment seasons it was observed that biomass production was different. In marine season *RA* recorded 8.4 g more than lagoon season at the same size. Results were used in order to discuss about atarraya nets uses, and to propose the implementation of a lagoon closure during July inside lagoon systems located in GT. With this proposal artisanal fishermen will be allowed to use atarraya nets with mesh opening of 25.4 mm during June, and they will obtain a good biomass production level as economic support.

Additionally, with new marine closure systems shrimp reproductive seasons will be protected (from July to November).

Keywords

Closure Systems, Gulf of Tehuantepec, Recruitment Age, Recruitment Seasons, White Shrimp

1. Introduction

The life history of the Penaeidae shrimps family is approximately between 15 and 18 months (Cervantes-Hernández, 2008 [1]), and this begins in the marine environment with the reproduction that generates shrimp post-larvae. After those enter lagoon systems for their protecting, feeding and growing until they are young shrimp (Gracia *et al.*, 1997 [2]). When young shrimp reach a total length ~80 mm they leave lagoon systems to return to the marine environment, and start life history again.

From the four commercial shrimp species that inhabit in the Gulf of Tehuantepec (GT), México (Figure 1), white shrimp *Litopenaeus vannamei* (Boone 1931) has been most studied species. For this shrimp population the following studies were done: mortality (Ramos-Cruz *et al.*, 2006 [3]), exploitation evaluation

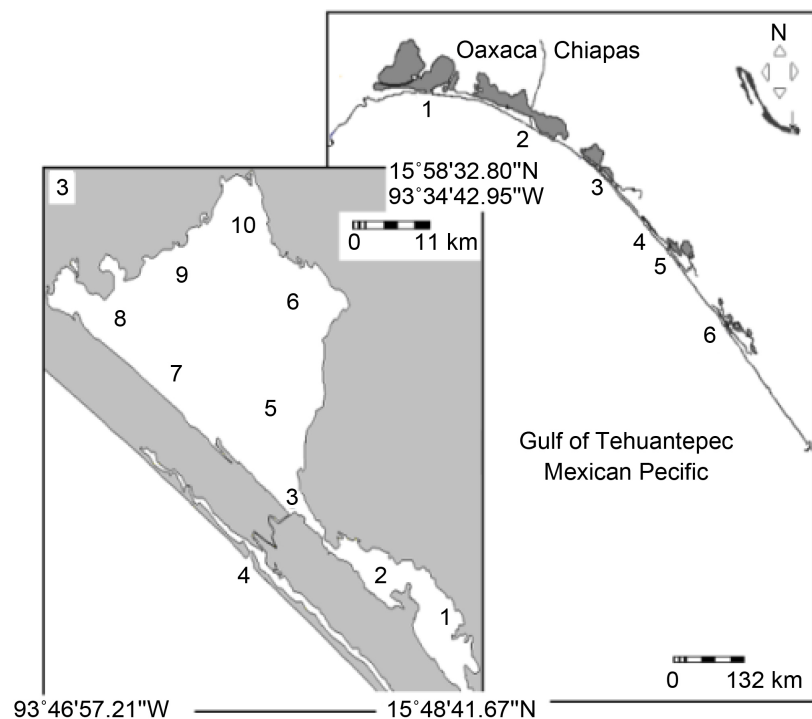


Figure 1. Geographic location of GT and the CTJB-LS. The lagoon systems from GT are: Huave (1), Mar Muerto (2), Cabeza de Toro la Joya Buena Vista (3), Patos Solo Dios (4), Carretas Pereyra (5), Chantuto Panzacola (6). Sampling stations are shown with the numbers from 1 to 10.

and closures (Cervantes-Hernández *et al.*, 2008 [4]), reproductive and recruitment seasons (Cervantes-Hernández *et al.*, 2008 [5]), and ecological distribution (Cervantes-Hernández and Egremy-Valdez, 2013 [6]). Based on the aforementioned literature, it was concluded:

1) The complete life history is approximately between 15 and 16 months (Cervantes-Hernández *et al.*, 2008 [4]).

2) The “Marine Recruitment” was defined as the natural movement of young shrimp from inside lagoon systems towards the marine environment of GT (Cervantes-Hernández *et al.*, 2012 [7]). In GT (Figure 1) a complete marine recruitment season spanned from April to August, with the highest recruit flow during June/July (Cervantes-Hernández *et al.*, 2008 [4]).

3) The “Lagoon Recruitment” was defined as the natural movement of post-larvae shrimp from the marine environment of GT towards inside lagoon systems (Cervantes-Hernández *et al.*, 2012 [7]). The white shrimp reproduces during the lagoon recruitment, and in the GT a complete lagoon recruitment season spanned from July to November, with the highest post-larvae flow during October (Cervantes-Hernández *et al.*, 2008 [4]).

In the marine environment of GT, the recruitment age of white shrimp was estimated at 4-m-olds (Cervantes-Hernández *et al.*, 2008 [4]), and inside CTJB-LS this age was reported between 4.5 and 5-m-olds (Cervantes-Hernández *et al.*, 2012 [7]). It was found that recruitment age has not been clearly identified, and information about total length (Lt) corresponding to each mentioned recruitment age is scarcely documented. For the mentioned problems, at present, it has not been easy to implement the best fishing net selectivity with the adequate mesh opening (atarrayas) to protect this resource inside lagoon systems located in GT (Ramos-Cruz, 2011 [8]). In this study mesh opening theme was taken into account only in the discussions, because the aim of this study was to generate biological information to propose the implementation of a lagoon closure inside lagoon systems in GT. This specific information was the recruitment age and the biomass production during the marine and lagoon recruitment seasons.

In the present study, dwell times inside lagoon (TL) were accounted for re-estimating with more exactitude the recruitment age of white shrimp. For explanation, the seasonality of biomass changes were analyzed records of Lt (in mm) and total weight (Pt in gr). Finally, conclusions were made considering relationship between recruitment age and Lt - Pt .

This study took as initial point of analysis, the results of Cervantes-Hernández *et al.*, 2012 [7] (Figure 2). For this reason, the present study was a continuation of this work. Obtained results and conclusions of this study are different to reported by these authors because they did not estimated TL and the seasonality of biomass changes.

2. Materials and Methods

For the present study, between April 25th 2001 and March 28th 2002, technical

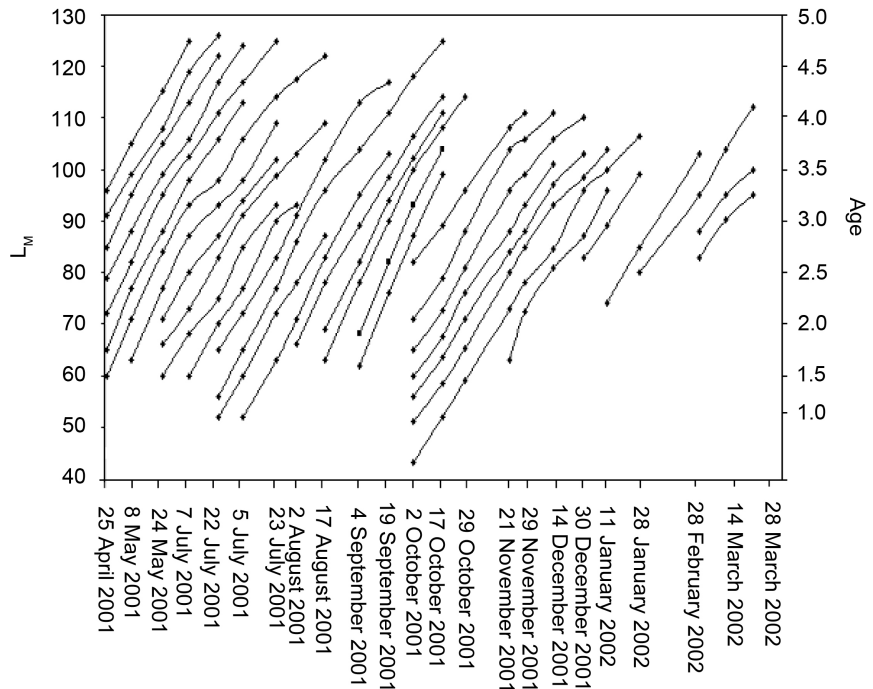


Figure 2. Modal progression analysis with 23 dates. Marine (from April to October 2001) and lagoon (from October 2001 to March 2002) recruitment seasons in the CTJB-LS. The *L. vannamei* cohorts are shown with 200 black circles, and each of those have an average length value (LM in mm), and their corresponding age in months. The cohorts were organized and connected diagonally with 34 progression lines. Each of those was drawn between a minimum value (initial cohort) and a maximum value (terminal cohort) of LM . Cervantes-Hernández *et al.*, 2012 [7].

personnel from the Centro Regional de Investigación Pesquera, Salina Cruz, Oaxaca, México (CRIP-SC), sampled young shrimp for determination of L_t and P_t from ten sampling stations inside CTJB-LS (Figure 1). Each sampling was done from 14 and 15 days, and young shrimp were caught using atarraya nets with mesh opening of 19 mm, and between 1 and 6 m. For each individual, L_t was measured from the rostrum tip to the telson end. Young shrimp were identified according to [4].

The information generated by CRIP-SC was analyzed at the Universidad del Mar, Puerto Ángel, Oaxaca, Mexico, under the 2IR1104 project. The analyses were done as follows:

2.1. TL Estimation

In the 34 progression lines all initial cohorts were identified (Figure 2), and after in each progression line TL was estimated taken into account the days that elapsed between initial and terminal cohort. In this case TL was expressed in months.

2.2. Recruitment

Estimated TL values were separated by recruitment seasons types, and with this

information a classification neuronal model (CNm) was conducted with three train layers (Haykin, 1999 [9]). Linear models were used in order to activate the synaptic signals and three train layers. CNm results were two probability trends with scale between 0 and 1 that were called dwell time inside lagoon during marine recruitment season $P(TL_{MR})$ and dwell time inside lagoon during lagoon recruitment season $P(TL_{LR})$. The first probabilistic trend was used for re-estimating the recruitment age and the second probabilistic trend was used in order to approximate youngest shrimp age inside CTJB-LS.

2.3. Increase in Length

White shrimp length parameters were estimated with 3,955 records of Lt arranged in age classes from 1 to 5-m-olds (Et) (Figure 2). The Pitcher and McDonald, 1973 [10] model was used:

$$L_{te} = L_{inf} \cdot \left(1 - \exp \left[-k \cdot (Et - t_o) + \frac{(k \cdot C)}{(2\pi)} \sin(2\pi(Et - t_s)) \right] \right) + \varepsilon \quad (1)$$

where L_{te} (estimated total length), L_{inf} (the asymptotic length), k (the metabolic growth rate in body length), t_o (the age at zero cm), C (oscillations magnitude), t_s (starting point of C), ε is the estimation error of L_{te} .

With estimated length parameters the *L. vannamei* length trend was conducted inside CTJB-LS. This length trend was complemented with a projection towards outside CTJB-LS where the adult shrimp population reaches the oldest age. According to Taylor 1958 [11], the oldest age was estimated with:

$$A_{0.95} = t_o + (2.996/k) \quad (2)$$

where the oldest age is called $A_{0.95}$ and 0.92 is the time required to obtain 95% of L_{inf} value.

2.4. Lt - Pt Relationship

White shrimp Lt - Pt relationship was evaluated with 6,148 records of Lt and Pt . According to Ricker 1975 [12], this relationship was estimated with:

$$Pt = a \cdot Lt^b + \varepsilon \quad (3)$$

where a is the intercept, b is the slope, and ε is the estimation error. Estimated b parameter was compared with $b = 3$ (isometric grow) in order to know how *L. vannamei* grew during marine and lagoon recruitment seasons. This analysis was evaluated with t-student distribution (Zar, 1999 [13]), and according to Ricker 1975 [12] when shrimp bodies grow equally in length and weight, resulted growth is isometric ($b = 3$). On the other hand, when shrimp bodies grow more in length than in weight, resulted growth type is negative allometry ($b < 3$), and the inverse is positive allometry ($b > 3$).

To estimate the parameters in the Equations (1)-(3), the Bayesian method of likelihood was used with the ε fitted to log-normal distribution (Haddon, 2011 [14]). Bayesian method of likelihood was conducted with PopTools 2.7.5 software, and CNm was executed with StatSoft® 7.0 software.

3. Results

3.1. TL Estimation

TL values are summarized in **Table 1**.

3.2. Recruitment

Results of this section are shown in **Figure 3**.

For the population of *L. vannamei* inside CTJB-LS, the real age structure resulted between 1 and 4-m-olds (**Figure 2**). During marine recruitment season it was observed that when age increased the $P(TL_{MR})$ gradually descended. Estimated $P(TL_{MR}) = 0.50$ was taken into account as the midpoint of change in order to understand how young shrimp with 3-m-olds started leaving the CTJB-LS ($P(TL_{MR}) > 0.5$), and how the rest remained inside CTJB-LS ($P(TL_{MR}) < 0.5$). Young shrimp in 4-m-olds showed the minimal $P(TL_{MR})$ value, and ages > 4 -m-olds were not found inside CTJB-LS. Based on the aforementioned, it was concluded that young shrimp migration elapsed between 3 and 4-m-olds, with the highest recruit flow in 4-m-olds. This last age was called the recruitment age of *L. vannamei*.

Table 1. Dwell times inside lagoon (TL) of young *L. vannamei* during marine (MR) and lagoon (LR) recruitment seasons inside CTJB-LS. With reference to **Figure 2**, the following are designated number to progression lines (LP), total cohorts number (TC).

RM	LP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	TC	4	5	5	6	7	6	9	6	5	7	5	5	7	9	5	6	6	5	6	4	4
	TL (months)	2.4	2.9	2.9	3.4	3.9	3.4	3.7	3.4	2.5	3.3	2.5	1.8	2.9	3.9	1.9	2.5	2.5	2.0	2.4	1.5	1.5
RL	LP	22	23	24	25	26	27	28	29	30	31	32	33	34								
	TC	5	6	7	6	7	8	9	5	3	3	4	3	3								
	TL (months)	1.9	2.4	2.9	2.4	2.9	3.4	3.9	1.7	1.0	1.6	2.0	1.0	1.0								

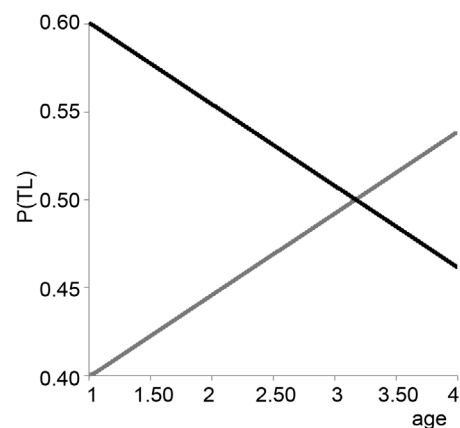


Figure 3. Dwell time inside lagoon (TL), and their probabilistic trends during marine $P(TL_{MR})$ (dark line) and lagoon $P(TL_{LR})$ (gray line) recruitment seasons in the CTJB-LS.

During lagoon recruitment season it was observed that when age increased the $P(TL_{MR})$ gradually ascended. Estimated $P(TL_{MR}) = 0.50$ was taken into account as the midpoint of change in order to understand how young shrimp between 3 and 4-m-olds started to have a relevant presence inside CTJB-LS ($P(TL_{MR}) > 0.5$), and how the rest did not show a relevant presence ($P(TL_{MR}) < 0.5$). Young shrimp in 1-m-old recorded the value of 0.40 in $P(TL_{MR})$, and based on this it was concluded that post-larval could not be detected inside CTJB-LS until they reach 1-m-old (youngest shrimp age).

3.3. Increase in Length

Results of this section are shown in **Figure 4**.

The ages that frequently entered and developed inside CTJB-LS were identified between 1 and 4-m-olds (**Figure 3**), and for this age structure the L_t ranked from 51 to 106 mm (**Figure 4**). The $A_{0.95}$ was estimated at 19-m-olds reaching the asymptotic length at 205 mm.

3.4. L_t - P_t Relationship

Results of this section are summarized in **Table 2** and **Figure 5**.

White shrimp L_t - P_t relationship resulted almost equal in both recruitment seasons ($F = 3.25$, $F_{0.05(1,6146)} = 3.84$, $p > 0.05$). But based on estimated b parameters,

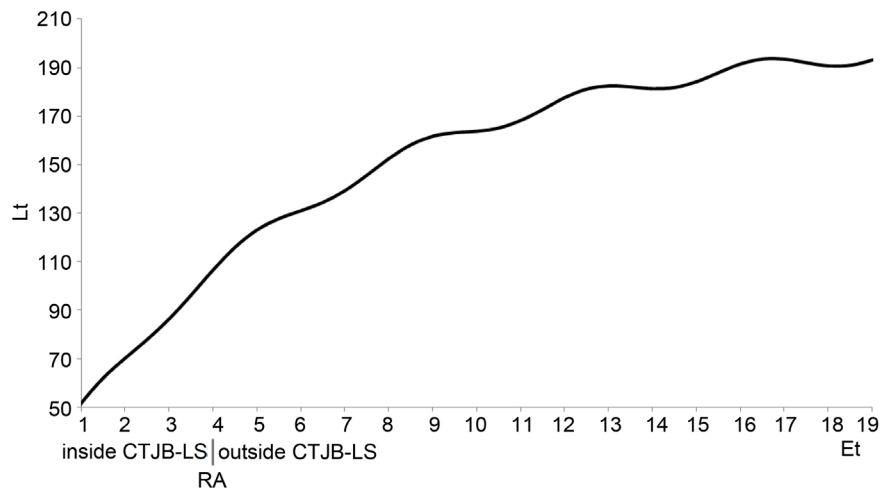


Figure 4. Complete length trend for *L. vannamei*, April 25th 2001 - March 28th 2002 period. Total length (L_t in mm), recruitment age (RA in months), the age structure (Et in months). Estimated length parameters: $L_{inf} = 205$ mm, $k = 0.15$ monthly, $t_0 = -0.76$ mm, $C = 0.65$, $t_s = 0.25$. Final estimated model: $L_{te} = 205 \cdot 1 - \exp^{[-0.152(Et - (-0.76)) + (0.15 \cdot 0.65) / (2\pi) \sin(2\pi(Et - (-0.25)))]}$.

Table 2. Estimated parameters in L_t - P_t relationship. Intercept (a), slope (b), determination (r^2), size sample (n), significance level (p).

	a	b	r^2	n	p
marine recruitment season	-5.19	3.04	0.96	3,955	<0.05
lagoon recruitment season	-4.88	2.88	0.96	2,193	<0.05

it was concluded that during marine recruitment season Lt - Pt relationship was isometric (ho: $3.04 = 3.00$, $t = 0.87$, $t_{0.05(1),3,953} = 1.64$, $p > 0.05$), and during lagoon recruitment season this relationship was negative allometry (ha: $2.88 < 3.00$, $t = 10.81$, $t_{0.05(1),2,191} = 1.64$, $p < 0.05$).

The highest biomass production was recorded inside CTJB-LS during marine recruitment season (Figures 2-6), and this was explained by the high cohorts number that reached the recruitment age with 8.4 g and > 106 mm. The lowest biomass production was recorded inside CTJB-LS during lagoon recruitment season (Figures 2-6), and this was explained by the low cohorts number that reached the recruitment age with 7.6 g and > 106 mm.

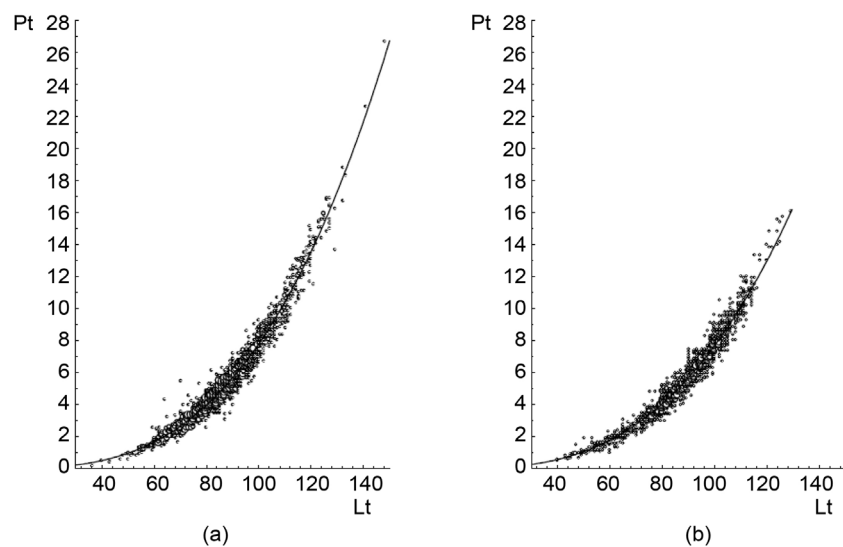


Figure 5. Lt - Pt relationship models for *L. vannamei*, April 25th 2001-March 28th 2002 period. Total length (Lt in mm), total weight (Pt in gr). Estimated model for marine recruitment season: $Pt = -5.19 \cdot Lt^{2.04} + \varepsilon$, and estimated model for lagoon recruitment season: $Pt = -4.88 \cdot Lt^{2.88} + \varepsilon$.

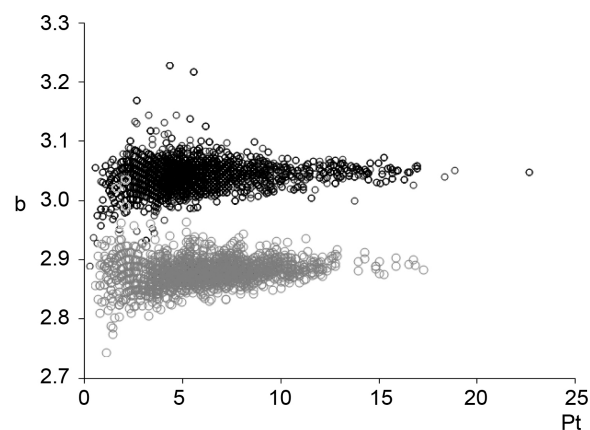


Figure 6. Total weight (Pt in gr) vs. b parameter. During marine recruitment season Lt - Pt relationship was isometric ($b = 3$, black pints), and shrimp bodies grow equally in length and weight. During lagoon recruitment season Lt - Pt relationship was negative allometric ($b < 3$, gray points), and shrimp bodies grow more in length than in weight.

4. Discussion

4.1. TL Estimation and Recruitment

The region of GT is influenced by northerly winds from the Gulf of Mexico, which produce intense upwelling during winter Tehuanos seasons between November and February (Fernández-Álamo *et al.*, 2000 [15]). The upwelling process generates an ascension of cooler deep water and an elevated concentration of nutrient due to the rupture of the thermocline (González-Silvera *et al.*, 2004 [16]). These characteristics induce a complex oceanographic pattern with cyclonic and anticyclonic eddies that affect the concentration of chlorophyll *a* (Cl-*a*), primary productivity, and spatial distribution of organisms (Gallegos-García and Barberán-Falcón, 1998 [17]; Monreal-Gómez and Salas de León, 1998 [18]; Farber-Lorda *et al.*, 2004 [19]). Lara-Lara *et al.*, 1998 [20] mentioned that outside winter Tehuanos seasons (during rainy seasons between May and October), in the region of GT lower Cl-*a* and primary productivity values were documented, and these were generated mainly by the local fluvial discharge.

As was established for *L. vannamei*, marine recruitment seasons spanned from April to August, with the highest recruit flow during June/July. These seasons coincided with the rainy seasons, when lower reproductive activity was documented. Reproductive seasons spanned from July to November, with the highest post-larvae flow during October (Cervantes-Hernández *et al.*, 2008 [4]).

Inside lagoon systems rainfall and fluvial discharge impose osmoregulatory limitations that stimulate young shrimp migration toward marine environments (Ruello, 1973 [21]; Cruz-Orozco and Ley-Lou, 1980 [22]; García and Le Reste, 1986 [23]; Cervantes-Hernández, 2015 [24]). Browder and Moore 1981 [25] mentioned that fresh water flow into coastal body of water increases shrimp production because mineral, organic matter and turbidity increases (Penn and Caputi, 1986 [26]), and salinity with water temperature are reduced. García and Le Reste 1986 [23] indicated that environmental changes might delay or hurry shrimp migration.

In the Bank of Campeche, Mexico, Cervantes-Hernández 1999 [27] showed that marine recruitment of pink shrimp *Farfantepenaeus duorarum* (Burkenroad 1939) has a relationship with accumulated rainfall and fluvial discharge since 2 and 1 months, respectively, before maximum recruitment occur. Similar results were documented by Gracia and Soto 1990 [28] in white shrimp *Litopenaeus setiferus* (Linnaeus 1767).

In this study, it was concluded that young recruits migration toward outside CTJB-LS elapsed between 3 and 4-m-olds, with the highest recruit flow in 4-m-olds. Thus this last age was called the recruitment age of *L. vannamei* (Figure 3). The young of *L. vannamei* from 83 to 120 mm were documented as present marine environment in front of the Mar Muerto, CTJB-LS, Chantuto-Panzacola y Carretas-Pereyra lagoon systems, Oaxaca-Chiapas, Mexico (Figure 1) (Ramos-Cruz, 2011 [29]). Specific ages for these sizes were not reported but based on Figure 4, it was suggested that these ages should be between

3 and 5-m-olds.

A recruitment age in 4-m-olds was documented for brown shrimp *Farfantepenaeus californiensis* (Holmes 1900) in GT (Cervantes-Hernández, 2008 [1]; Cervantes-Hernández *et al.*, 2008 [4]), and brown shrimp *Farfantepenaeus aztecus* (Ives, 1891) in Tamaulipas-Veracruz region, Gulf of Mexico (Cervantes-Hernández, 2015 [24]). The young of *L. vannamei* and *F. aztecus* with 3-m-olds were documented as present in the marine environments from gulfs of GT and Mexico (Cervantes-Hernández *et al.*, 2008 [4]; Cervantes-Hernández, 2015 [24]). Due to its lower finishing mortality rates (F) and abundances these ages were reported underexploited, and partially recruited to the adult population. Monthly F values were estimated at $F = 0.01$ (Ramos-Cruz *et al.*, 2006 [3]), and $F = 0.02$ (Cervantes-Hernández, 2015 [24]), respectively. In this study, this specific age was considered such as the minimum recruitment age inside CTJB-LS.

4.2. Increase in Length and *Lt-Pt* Relationship

Inside CTJB-LS the recruitment age of *L. vannamei* was reported between 4.5 and 5-m-olds (Cervantes-Hernández *et al.*, 2012 [7]), but in this study ages > 4-m-olds were not found in this lagoon system. These specific ages were considered as the maximum recruitment ages that can be found outside CTJB-LS (Ramos-Cruz, 2011 [29]), completely recruited to the adult population (*Lt*~125 mm y *Pt*~14 g) (Figure 4 & Figure 5). The aforementioned was true, because the sexual maturity age is generally reached between 6 and 7-m-olds as in cases of *F. californiensis* (Cervantes-Hernández, 2008 [1]), *F. aztecus* (Cervantes-Hernández, 2015 [24]) y *L. vannamei* (Cervantes-Hernández *et al.*, 2008 [4]). For those species the entire population is sexually mature between 11 and 16-m-olds.

Based on the information mentioned in the literature a new conclusion was done. In brief, in optimal environmental conditions (mainly rainfall and fluvial discharge), in CTJB-LS young recruits migration occurs during marine recruitment seasons between 3 and 5-m-olds, with the highest recruit flow in 4-m-olds. Environmental changes might delay (dominant ages in 5-m-olds) or hurry (dominant age in 3-m-olds) young recruits migration. The first case was documented by different authors, and this was explained due to excesses in the built of reservoirs and environmental pollution (Cervantes-Hernández, 2015 [24]; Cervantes-Hernández *et al.*, 2012 [30]; 2017 [31]). The 5-m-olds age was documented in relation with delay young recruits migration (Solana-Sansores *et al.*, 1989 [32]; Hannah, 1999 [33]). The second case has relationship with the prolonged development of rainfall and fluvial discharge periods.

As was established, during marine recruitment season the recruitment age recorded 8.4 g with *Lt* at 106 mm, and during recruitment season, the *Pt* reduced by 0.8 g at the same *Lt* value (Figure 6). Ramos-Cruz (2011) [29] recorded 6.0 g in the youngest recruits of *L. vannamei*. Specific age for this weight was not reported but based on Figure 4, it was suggested that this age should be 3-m-olds

with Lt at 80 mm. This author did not consider differences between marine and lagoon recruitment seasons in order to estimate the following Lt - Pt relationship model: $Pt = 0.0000283 \cdot Lt^{3.22} + \varepsilon$. The author did not conclude on this model but considering that $b = 3.22$, it was suggested that during study period Lt - Pt relationship was positive allometry ($b > 3$).

Since 1976 in lagoon systems located in GT, the artisanal catch of *L. vannamei* and *F. californiensis* has been done with atarraya nets with mesh opening of 25.4 mm (Ramos-Cruz, 2011b [8]). PESCA 1997 [34] indicated that the artisanal catch must be done with atarraya nets with mesh opening of 38.1 mm, but this mesh opening really have never been used in GT. With the first mesh opening mentioned by [8] the length catch ranked from 60 and 120 mm, and with suggested ages between 1.5 and 4.5-m-olds (Figure 4). On the other hand, with an atarraya nets with mesh opening <25.4 mm the length catch was <80 mm (<3-m-olds). It was considered that these mentioned data were not correct because the artisanal catch of this study was obtained with mesh opening of 19 mm, and the age catch ranked from 1 and 5-m-olds. Thus, it was concluded that atarraya nets with mesh opening between 19 to 25.4 mm generate the same range of catch for shrimp length and age. Ramos-Cruz, 2011 [8] reported in activity atarraya nets with mesh opening from 9.5 to 25.4 mm.

The discussion about which mesh opening should be used to protect shrimp recourse in GT is open, and in this study we did not recommend a mesh opening to use inside lagoon systems because we do not have a scientific base to support this, instead shrimp artisanal catch can carry on like ever, but the following should be taken into account:

- 1) Atarraya nets with mesh opening of 25.4 mm can be used during complete lagoon recruitment seasons because as was established before, in CTJB-LS biomass production was lower. This same should be done in the other lagoon systems located in GT.

- 2) During marine recruitment seasons atarraya nets with mesh opening of 25.4 mm only can be use from April to May when biomass production and young recruits migration begin to increase. All fishing methods shall be prohibited from June to July because in this period maximum young recruits migration occurs (Figure 2). Details in the literature (Cervantes-Hernández, 1999 [27]; 2008 [1]; 2015 [24]; Cervantes-Hernández *et al.*, 2008 [4]; 2012 [7]; 2017 [31]).

The marine shrimp fishery has been regulated in Mexican Pacific through closure systems, and these were documented as follow: from July to September (between 1979 and 1987), from May/April to September (between 1993 and 1997) (Cervantes-Hernández *et al.*, 2008 [4]), from April to September 1999, and afterwards of 2001 from March/April to September (INAPESCA, 2007 [35]). In GT, closure periods have not worked because these periods were focused on protecting marine recruitment seasons, and lagoon recruitment seasons were only partially included. In the literature if was found that *L. vannamei* reproductive seasons spanned from June to November, with the highest post-larvae flow

during October (Cervantes-Hernández *et al.*, 2008a [4]). In the case of *F. californiensis* reproductive seasons spanned July to February, with the highest post-larvae flow during October/November (Cervantes-Hernández, 2008 [1]; Cervantes-Hernández *et al.*, 2008 [4]).

The last authors mentioned proposed a new closure system to protect shrimp reproductive seasons exclusively in GT. This closure system was reported from June/July to October, and afterward this was ratified by Cervantes-Hernández *et al.* 2017 [31] from July to November. To manage the artisanal shrimp catch, the second choice should be better because during July a lagoon closure can be established inside lagoon systems located in GT. This new proposal will allow for artisanal fishermen to use atarraya nets with mesh opening of 25.4 mm during complete June, and they will obtain a good biomass production level as support (Figure 6).

From the beginning, the results published on marine closure system changes in GT were not accepted by the fishery community in Oaxaca because those studies did not include lagoon recruitment information in their fishery models. At present, shrimp fishery in GT is reported on a critical level of overexploitation (Cervantes-Hernández *et al.*, 2006 [36]). A lagoon closure was proposed by Barrera-Huerta in 1976 [37], and this was not taken into account due to a lack of ecological, biological and fishery analysis. Now, *L. vannamei* fishery has complete population analysis in order to influence possible closure system changes. This information is a guide to plan *F. californiensis* fishery because both fisheries in GT reproduce almost at the same time.

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