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Short Communication

Biometric relationships for commercially important penaeid shrimp species on the east coast of the Gulf of California

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ABSTRACT. Biometric relationships were estimated for the three most important shrimp species on the coasts of the Gulf of California, Mexico. Individuals were obtained from six lagoon systems, and offshore sites along the east coast of the Gulf of California, mainly in the state of Sonora, between March and September of 2015 and 2016. A total of 25,764 individuals of *Penaeus stylirostris*, *Penaeus vannamei* and *Farfantepenaeus californiensis* were analyzed; the length and weight regression for the females, males and combined sexes showed a high correlation between variables. Additionally, some statistically significant differences were found in the linear length and weight relationships ($P < 0.05$) between sexes. This study reports the length-weight parameters for a key site of the shrimp fishery, it covers a wide range of sizes for each species and was based on the stages late inshore juvenile and offshore of the shrimp lifecycle; as such, this study provides useful information for future estimations of indispensable parameters for stock assessment analyses.

Keywords: Penaeidae; blue shrimp; brown shrimp; length-weight; Sonora; Mexico

Penaeid shrimps have commercial importance in tropical and subtropical seas, and the annual world catch is estimated at 1 Mt per year, with the majority harvested by trawlers (Kelleher, 2005; Gillett, 2008). The shrimp fishery is one of the most important fisheries in Mexico because it provides important social and economic benefits. On the Pacific coast, Sonora and Sinaloa support the main part of the fishery within the Gulf of California (*e.g*., 85% of the total catch). The brown shrimp *Farfantepenaeus californiensis* (Holmes, 1990), blue shrimp *Penaeus stylirostris* Stimpson, 1871 and white shrimp *Penaeus vannamei* Boone, 1931 are the three most important commercial species that are exploited at various stages of life cycle by artisanal and industrial fisheries (Gillett, 2008; Dubay *et al*., 2010; CONAPESCA, 2017). *F. californiensis* constitutes the base of the offshore catch (*e.g*., 70-80% of the industrial fleet), while *P. stylirostris* and *P. vannamei* comprise the base of the shrimp fishery in bays and coastal lagoons (*i.e*., the artisanal fleet). In this multi-specific fishery, the management strategy consists of setting a seasonal closure between April and August to prevent growth overfishing during the spawning season. The seasonal closure help to decreases the catch of juveniles during the recruitment period, included in the main regulatory measures (NOM-002-PESC-1993). This Mexican Official Standard has provisions for control and reduction of fishing effort (number of boats), closed seasons and closed areas (Gillett, 2008).

The information on the length-weight relationships is necessary to determine the conversion equations from growth in length to growth in weight, which will

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be used for the estimation of indispensable parameters in the stock assessment analysis (Al Nahdi *et al*., 2016; Freitas *et al*., 2017). In penaeid studies, measurements of certain lengths, rather than weights, are usually recorded in samplings campaigns. Globally, some authors have provided biometrics relationships for commercial penaeid shrimp, particularly *Penaeus* genus (Fontaine & Neal, 1971; Rodríguez de la Cruz, 1981; Chu *et al*., 1995; Pérez-Castañeda & Defeo, 2002; López-Martínez *et al*., 2005; Ramos-Cruz, 2012). However, in some important global shrimp catch areas, there is no information about the biometric relationships of these commercial shrimp (*Penaeus* genus), or the information comes from an old information.

Even though the Gulf of California is the most important shrimp catch area for Mexico, there is little information about the biometric relationships of these commercial shrimps. The existent information about this topic comes from small sample sizes, samples collected at certain times in the species life cycles or from only commercial catches (Menz & Bowers, 1980; Rodríguez de la Cruz, 1981; López-Martínez *et al*., 2005). This study presents the biometric relationships for the three commercially important penaeid shrimp (*e.g*., *F. californiensis*, *P. stylirostris* and *P. vannamei*) on the east coast of the Gulf of California. With the purpose to cover a wide range of sizes for each shrimp species, the length and weight information coming from two years of intense sampling (2015-2016). Additionally, sampling was conducted using different fishing gears and different areas, based on the life cycle of each species.

Collection of specimens

Shrimp samples were collected from March to September in 2015 and 2016 (when the shrimp fishing season is closed) along the east coast of the Gulf of California, mainly in the state of Sonora (Fig. 1). Specifically, monthly biological surveys (from March to September) were conducted inside and outside each of six lagoon systems (*e.g*., Bahía de Kino, Las Guásimas, Bahía de Lobos, El Tobari, Yavaros and Agiabampo). The sampling stations correspond to those established and sampled annually by the Instituto Nacional de Pesca and Acuacultura (INAPESCA, a Mexican Fisheries Research Institution) to assess the shrimp populations. Sampling stations were spread across the shrimp fishing grounds at depths ranging from 0.5 to 8 m deep. The fishing gears used in these surveys were shrimp trawl nets (8-9 m float line and 35 mm liner at the codend), gillnets (44, 50, 57 and 60 mm mesh size) and cast nets (25 to 44 mm mesh size). Moreover, during July-August of 2015, 2016, research cruises were conducted in the coastal waters of Sonora (7 to 54 m deep), from Bahía de Kino to Agiabampo (Fig. 1). These sampling stations also correspond to those established by INAPESCA. The fishing gears deployed from the vessels consisted of paired shrimp trawls nets (30.5 m float line and 45-50 mm mesh size), which are typical of the commercial shrimp fleet in the Gulf of California.

Data measurement

Shrimp were separated by species (*F. californiensis*, *P. stylirostris* and *P. vannamei*) (Ma *et al*., 2011). Their abdominal and total length (*i.e*., from the tip of the rostrum to the tip of the telson in the extended specimen, in mm) was measured to the nearest millimeter with an ichthyometer, and total and abdominal weight was recorded to the nearest 0.01 g using an electronic balance.

Statistical analysis

The abdominal length/total length (AL/TL) relationships for the three shrimp species were estimated separately for males and females and for both sexes, and data from 2015 and 2016 were assessed using the following expressions: $TL = a + b \times AL$, where TL is the total length (mm), AL is the abdominal length (mm), a is the intercept and b is the slope.

The total-length/total-weight (TL/TW) and abdominal-length/abdominal-weight (AL/AW) relationships were estimated for males and females separately, and then for both sexes together. Data from 2015 and 2016 were assessed using the equations: $TW = a \times TL^b$ and $AW = a \times AL^b$, where W is the weight (total or abdominal), L is the length (total or abdominal), a is the coefficient of proportionality and b is the coefficient of allometry. These equations assume that the relative body proportions of the individuals increase based on the last two parameters. The equation was linearized: $\log W= a + b \times \log L$. Log-log plots of the length-weight pairs were created to identify outliers, and extreme outliers were excluded from the analysis (Froese *et al*., 2006). For all equations, the coefficient of determination (R^2) was used as the index of the strength of the linear association, and the 95% confidence limits for a and b were calculated.

Statistically significant differences in linear relationships between sexes were evaluated through a one-way covariance analysis (ANCOVA), where the dependent variable was the weight and the covariate the length. ANCOVA was used once the assumptions of slope homoscedasticity were found, and after data were log- transformed (Zar, 2009).

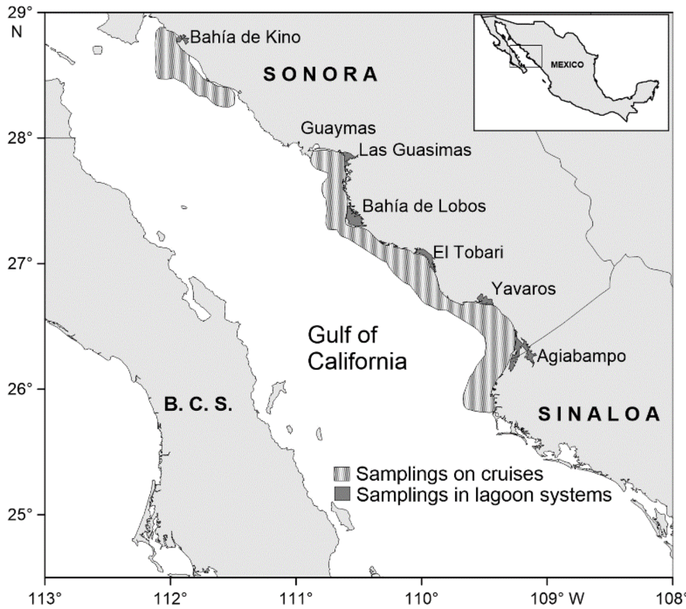

Figure 1. Study area where the shrimps were collected inside and outside of six lagoon systems (0.5-8 m deep) and offshore (7-54 m deep), along the east coast of the Gulf of California.

Table 1. Sex ratio (F:M), minimum and maximum length and the basic statistics for the three shrimp species (*Penaeus stylirostris*, *Penaeus vannamei* and *Farfantepenaeus californiensis*) used in the AL/TL regression analyses. Mean, median and standard deviation (SD) were calculated using only for the total length data. F: females, M: males.

Species	Sex	n	AL (mm)	TL (mm)	Mean	Median	SD
P. stylirostris	F	4011	28 - 153	46 - 242	135	140	31.76
	M	2722	29 - 137	47 - 212	143	147	23.07
F. californiensis	F	10822	31 - 145	50 - 223	132	133	35.32
	M	7280	32 - 138	50 - 207	117	119	22.35
P. vannamei	F	608	32 - 142	48 - 215	121	113	32.73
	M	321	44 - 135	78 - 196	127	123	27.31

A total of 25,764 individuals of *P. vannamei* (929), *P. stylirostris* (6,733) and *F. californiensis* (18,102) were analyzed. The sex ratio, minimum and maximum length (abdominal and total length), maximum length and weight (total-length and total-weight), and basic statistics for the three shrimp species are presented in Tables 1 and 2. The length-frequency distributions of measured shrimp were separated by species and sex, and used by the length regression analysis; these results are shown in Figure 2. It can be observed that there was a wide range of sizes for each shrimp species, which denotes intense sampling with different fishing gears and different samplings areas, based on the stages late inshore juvenile and offshore of the shrimp's lifecycle.

The length regressions for females, males and combined data for the three shrimp species (*i.e.*, blue, brown and white) showed high correlation according to the coefficients of determination ($R^2 > 0.970$ in all cases). Statistically significant differences in the linear length relationships ($P < 0.05$) were found between sexes for the three shrimp species (Table 3).

A total of 10,057 individuals of *P. vannamei* (451), *P. stylirostris* (3,834) and *F. californiensis* (5,772) were used for the length-weight relationship analysis. The length-frequency distribution of measured shrimp was separated by species and sex, and used by the length-weight regression analysis; these results are shown in Figure 2.

The weight regressions for females, males and both sexes of the three shrimp species (*i.e.*, blue, brown and white) showed high correlations between variables, according to the coefficients of determination ($R^2 > 0.970$ in all cases; Table 4). Statistically significant differences in the log-linear weight relationships ($P < 0.05$) were found between sexes for *F. californiensis*. *P. stylirostris* showed a significant difference between sexes in the total length-total weight relationship, but there was no significant difference between sexes in the

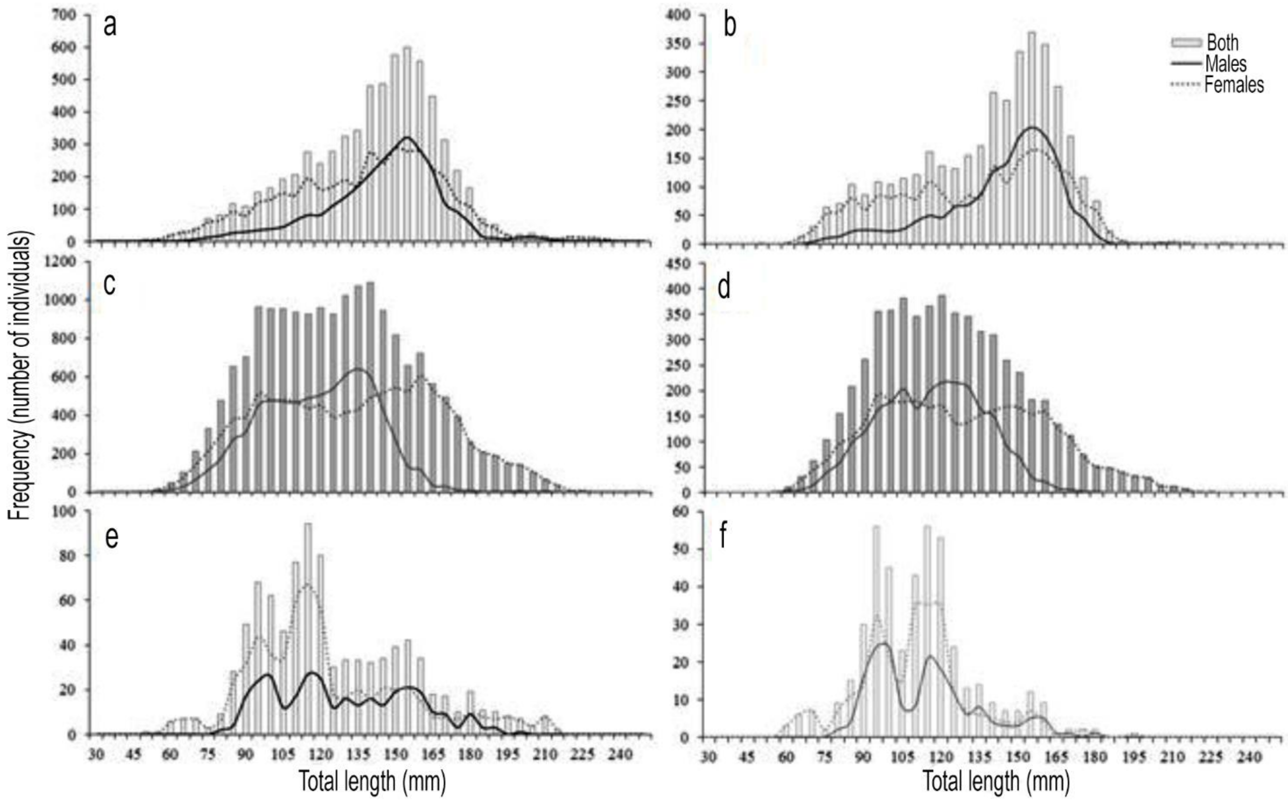

Figure 2. Sizes distribution for a-b) *Penaeus stylirostris*, c-d) *Farfantepenaeus californiensis,* and e-f) *Penaeus vannamei* used in the AL/TL (a,c,e) and L/W (b,d,f) regression analyses.

Table 2. Sex ratio (F:M), minimum and maximum total-length (mm)/total-weight (g), and the basic statistics for the three shrimp species (*Penaeus stylirostris*, *Penaeus vannamei* and *Farfantepenaeus californiensis*) used in the TL/TW regression analyses. F: females, M: males.

Species	Sex	n	TL (mm)	Mean	Median	SD	TW(g)	Mean	Median	SD
P. stylirostris	F	2191	57 - 226	131	137	31.27	1.2 - 89	20.4	19.2	13.68
	M	1643	62 - 205	141	147	23.04	2.0 - 73	23.6	24.3	10.59
F. californiensis	F	3341	55 - 222	127	125	32.78	1.3 - 103	20.5	16.0	15.46
	M	2431	57 - 207	114	115	20.67	1.5 - 81	13.1	12.1	6.93
P. vannamei	F	277	57 - 195	108	109	22.28	1.6 - 66	11.3	10.3	8.18
	M	174	78 - 177	112	111	20.66	2.9 - 45	12.4	10.9	8.39

abdominal length/abdominal weight relationship ($P > 0.05$). Finally, *P. vannamei* did not show significant differences between sexes in any log-linear weight relationships ($P > 0.05$).

This study conducted intense sampling with different fishing gears and different samplings areas; the design attempted to cover most of the habitat for each shrimp species based on the stages late inshore juvenile and offshore of shrimp's lifecycle. With this method of analyzing information, the effect of selectivity of single fishing gear was reduced, which causes having a narrow range of sizes, and also generated less accurate estimates of parameters derived from that size structure (López-Martínez *et al*., 2005). As a consequence, there is a wide range of sizes and weights for the three shrimp species (Tables 1-4), which provides more robust results.

Considerable variability in the biometric relationships may occur within shrimp species; this variability depends on the season, the differences in environmental conditions or the population; under this premise, the knowledge of specific biometric relationships for species and area must be assessed.

These studies are useful for estimating some measure of weight or some corporal measure that corresponds to a given length, and this provides a quantitative measure of biomass as well as other impor-

Table 3. Summary of the length regression for females only, males only and combined data for the three shrimp species (*Penaeus stylirostris*, *Penaeus vannamei* and *Farfantepenaeus californiensis*). F and *P* are values of the covariance analysis.

Species/Sex	Equation	Confidence interval 95%		R^2	F (ANCOVA)	*P* (ANCOVA)
		a	*b*			
P. stylirostris						
Females	TL =	1.487 ± 0.005	10.404 ± 0.460	0.986	121.471	<0.0001
Males	TL =	1.430 ± 0.008	14.398 ± 0.725	0.978		
Both	TL =	1.467 ± 0.004	11.660 ± 0.391	0.984		
F. californiensis						
Females	TL =	0.635 ± 0.001	1.312 ± 0.154	0.991	415.632	<0.0001
Males	TL =	1.498 ± 0.004	2.856 ± 0.343	0.983		
Both	TL =	0.673 ± 0.001	1.241 ± 0.123	0.989		
P. vannamei						
Females	TL =	1.477 ± 0.010	4.332 ± 0.863	0.992	5.995	0.015
Males	TL =	1.398 ± 0.017	10.073 ± 1.534	0.986		
Both	TL =	1.452 ± 0.009	6.025 ± 0.784	0.989		

Table 4. Summary of the weight regression for females only, males only and combined data for the three shrimp species (*Penaeus stylirostris Penaeus vannamei* and *Farfantepenaeus californiensis*). F and *P* are values of the covariance analysis.

Species/Sex	Equation	Confidence interval 95%		R^2	F (ANCOVA)	*P* (ANCOVA)
		a	*b*			
P. stylirostris						
Females	log TW=	-13.168 ± 0.078	3.278 ± 0.016	0.986	7.453	0.006
	log AW=	-11.412 ± 0.063	3.129 ± 0.014	0.987	2.086	0.149
Males	log TW=	-13.214 ± 0.108	3.290 ± 0.021	0.981		
	log AW=	-11.259 ± 0.076	3.094 ± 0.017	0.986		
Both	log TW=	-13.193 ± 0.061	3.288 ± 0.012	0.985		
	log AW=	-11.356 ± 0.047	3.116 ± 0.010	0.987		
F. californiensis						
Females	log TW=	-5.233 ± 0.022	3.072 ± 0.010	0.989	152.834	< 0.0001
	log AW=	-4.736 ± 0.020	3.015 ± 0.010	0.989	181.686	< 0.0001
Males	log TW=	-5.071 ± 0.035	2.987 ± 0.017	0.978		
	log AW=	-4.588 ± 0.035	2.928 ± 0.018	0.974		
Both	log TW=	-5.213 ± 0.018	3.059 ± 0.009	0.986		
	log AW=	-4.718 ± 0.018	3.002 ± 0.009	0.985		
P. vannamei						
Females	log TW=	-5.427 ± 0.089	3.155 ± 0.044	0.986	0.201	0.654
	log AW=	-4.992 ± 0.093	3.143 ± 0.050	0.983	0.169	0.681
Males	log TW=	-5.730 ± 0.118	3.303 ± 0.057	0.986		
	log AW=	-4.868 ± 0.163	3.078 ± 0.057	0.984		
Both	log TW=	-5.519 ± 0.071	3.201 ± 0.035	0.986		
	log AW=	-4.939 ± 0.070	3.115 ± 0.037	0.983		

tant biological aspects as, such as describing the growth pattern by evaluating the allometric coefficients and determining morphometric comparisons and stock structures. Further, deviations from this general relationship have been used to monitor the relative state of health of a given population (Cone, 1989; Ecoutin *et al.*, 2005; Froese, 2006). The length and weight regressions in females, males and combined data for the three shrimp species showed high correlation (R2 > 0.970 in all cases); suggesting a good adjustment of the data; this may be a consequence of the sample size and wide range of sizes and weights that were analyzed for each species in this study. Therefore, the use of the length-weight relationships presented here may not be limited to narrow ranges of length. In addition, the extensive sampling areas cover most of the habitat for each species based on the stages late inshore juvenile and offshore of the shrimp's lifecycle.

F. californiensis and *P. stylirostris* showed significant differences according to the total-length/total-weight relationship between sexes; however, no significant differences were observed in *P. stylirostris* about abdominal-length/abdominal-weight relationship between sexes. Similarly, *P. vannamei* did not show significant differences at any of the log-linear weight relationships between sexes. Anderson & Lindner in Fontaine & Neal (1971), noted that mature shrimp were heavier than immature individuals of the same length and that this difference caused seasonal changes in the length-weight relationship. Chu *et al*. (1995) mentioned that mature female of some penaeids (*e.g*., *Penaeus merguiensis*, *P. longistylus*, *P. latisulcatus* and *Metapenaeus ensis*) were commonly heavier than immature females of the same length.

In this research, the lack of significant differences in the log-linear weight relationships between sexes of *P. stylirostris* and *P. vannamei* is attributed to the fact that the overwhelming majority (>95%) of shrimp analyzed (*e.g*., females) were immature individuals. In contrast, in *F. californiensis*, 66% of the measured individuals were immature and 34% mature; this is due to the breeding strategy of this species, which occurs throughout whole year, individuals are smaller than the rest of the species (Leal-Gaxiola *et al*., 2001; Romero-Sedano *et al*., 2004), and mature individuals can be caught in lagoon systems and coastal waters during the whole year. According to the sampling dates in our study (*e.g*., March to September in lagoon systems and July to August in offshore sites), and considering the life cycles of *P. stylirostris* and *P. vannamei*, it was expected to catch mostly immature individuals. From June to September, the blue and white shrimp (*e.g*., juvenile and subadults) use lagoon systems as nursery areas, and individuals are still subadults when they start migrating to coastal waters (*e.g*., September). These species show interannual variability of the reproductive period, with a more intense spawning peak (*e.g*., a single cohort is more abundant in the catch) and it occurs offshore (Leal-Gaxiola *et al*., 2001; López-Martínez *et al*., 2005; Rivera-Velázquez *et al*., 2008); thus, we were not able to catch mature individuals in lagoon systems and coastal waters throughout the year. About linear length relationships, significant differences were found between sexes of the three shrimp species evaluated in this study. Fontaine & Neal (1971) detected similar results for white and brown shrimp in the Gulf of Mexico (Texas and Florida).

This research emphasizes the importance of biometric relationships studies for commercial fisheries in different ground fishing areas, useful information for future estimations of indispensable parameters for stock assessment analyses.

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