



Size at sexual maturity and growth of the red shrimp *Pleoticus muelleri* (Decapoda: Penaeoidea) captured artisanally in the Atlantic coast of Uruguay

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Abstract. Biological knowledge of the red shrimp *Pleoticus muelleri* in the Atlantic coast of Uruguay is scarce. The objective of this work is to provide the first information on size structure, size at first maturity and growth of the red shrimp. We registered 1842 red shrimps in two consecutive fishing seasons (2005-2006) in an artisanal fishery in Uruguay in Punta del Diablo town. Cephalothorax length-wet weight relationships (LWR) estimated were $WW=9.348E^{-4} CL^{2.77}$ and $WW=5.125E^{-4} CL^{2.99}$ for females and males respectively. LWR parameters showed shrimps being heavier at a given length further south. Mean size at first maturity CL_{50} (Confidence interval) were $CL_{50}= 32.28$ mm (31.69-32.87) for females and $CL_{50}= 25.08$ mm (24.60-25.55) for males. Total length vs cephalothorax length break point estimates of sexual maturity were 32 and 26 mm CL for females and males respectively. Seasonal Von Bertalanffy growth function showed that in both years, the females ($K= 1.36$ yr⁻¹ and $L_{\infty}= 53$ mm CL) grew slower, reaching a larger size at age than males ($K= 1.51$ yr⁻¹, $L_{\infty}= 35.5$ mm CL). Our results suggest that this species shows a higher growth into the warm waters, but its reproductive strategy remains unchanged in Argentina and Uruguay. This information could be applied directly in the management of this resource.

Keywords: shrimp, logistic regression, breakpoint analysis, growth

Resumen. Talla de madurez sexual y crecimiento en el langostino *Pleoticus muelleri* capturado artesanalmente en la costa Atlántica de Uruguay. La biología del langostino colorado, *Pleoticus muelleri* en la costa Atlántica de Uruguay es escasamente conocida. En el presente trabajo se provee información sobre la distribución de frecuencias de tallas, la talla de madurez para ambos sexos y los parámetros de crecimiento para esta especie en la costa uruguaya. Se registraron 1842 langostinos en dos zafra pesqueras artesanales consecutivas (2005-2006) en Uruguay (Punta del Diablo) donde se estimó la talla media de primera madurez (CL_{50}) y los parámetros de crecimiento. La relación Largo del cefalotórax-peso húmedo (LWR) estimada fue $WW=9.348E^{-4} CL^{2.77}$ para hembras y $WW=5.125E^{-4} CL^{2.99}$ para machos. El CL_{50} (Intervalo de Confianza) fue $CL_{50}= 32.28$ mm (31.69-32.87) para hembras y $CL_{50}= 25.08$ mm (24.60-25.55) para machos. Las estimaciones de la talla de primera madurez por punto de quiebre (BK) de la relación largo total vs largo del cefalotórax fueron 32 mm para hembras y 26 mm CL para machos. El crecimiento mostró que las hembras crecieron más lentamente y alcanzaron tallas superiores (K 1.36 año⁻¹ y 53 L_{∞} mm CL) que los machos (K 1.51 año⁻¹ y L_{∞} 35.5 mm CL). Los presentes resultados sugieren que el langostino en aguas uruguayas alcanza un mayor crecimiento pero las tácticas de su estrategia reproductiva se mantienen invariables respecto a lo observado en aguas de Argentina. Estas estimaciones son relevantes para la correcta gestión de este recurso pesquero.

Palabras clave: langostino, madurez sexual, regresión logística, análisis de quiebre, crecimiento

Introduction

The utmost importance of biological knowledge in exploited crustaceans has become evident in recent years in view of the collapse of

some noticeable fisheries (Orensanz *et al.* 1998). Unbiased demographic attributes such as the length frequency distribution, length-weight relationships, size at sexual maturity and gonadal maturity stages

and growth functions are crucial for managing resources (García & Le Reste 1986, Polet & Redant 1999). The classical method to estimate size at first maturity is based on fitting a logistic function and calculating the size class where a randomly chosen individual has 50% chance of being mature (Somerton 1980). Another method to estimate sexual maturity in crustaceans is based on finding changes in the allometry of some body parts generated due to abrupt shifts in growth of some body parts associated to sexual maturity (Hartnoll 1982). The use of a set of different methods is necessary to have accurate estimates of these relevant parameters.

Shrimps are important fishery resources worldwide (García & Le Reste 1986). The red shrimp *Pleoticus muelleri* (Bate 1888) is endemic to the Southwestern Atlantic Ocean, its distribution ranges from Rio de Janeiro (Brazil; 23° S) to Santa Cruz (Argentina; 50° S) (Holthuis 1980) where it is one of the most important fishery resource (Boschi 1989). In recent years, the artisanal fishing fleets located in the Uruguayan Atlantic coast have developed an artisanal red shrimp fishery. Nowadays, the Punta del Diablo-based artisanal fleet is exerting the highest fishing pressure on this resource in the Uruguayan waters (Segura *et al.* 2008). Despite it is one of the main fishery resources

in this zone and the increasing trend in the catches, knowledge of its reproductive biology and growth in the uruguayan Atlantic coast is scant.

In this context, the aim of the present paper is to provide the first information on the reproduction and growth parameters of this *P. muelleri* in Uruguayan coastal waters and compare them with estimates made further south. We have estimated: a) the length frequency distribution and length-weight relationships; b) the size at sexual maturity using two independent methods (*i.e.*, logistic regression and breakpoint analysis) and c) the parameters of the Von Bertalanffy Growth Function (VBGF) for the red shrimps captured artisanally in the Uruguayan Atlantic coast.

Materials and methods

Study area

Fishing grounds were located off Punta del Diablo (34° 30' S; 53° 00' W), a small fishing village in the Atlantic coast of Uruguay (Fig. 1). In austral winter (July-September) coastal waters are influenced by the diluted and cold (<27; 13°C) Subantarctic Shelf Waters. In austral summer (December-March) it is influenced by the saltier and warmer (>30; 23 °C) Subtropical Shelf Waters (Guerrero *et al.* 1997).

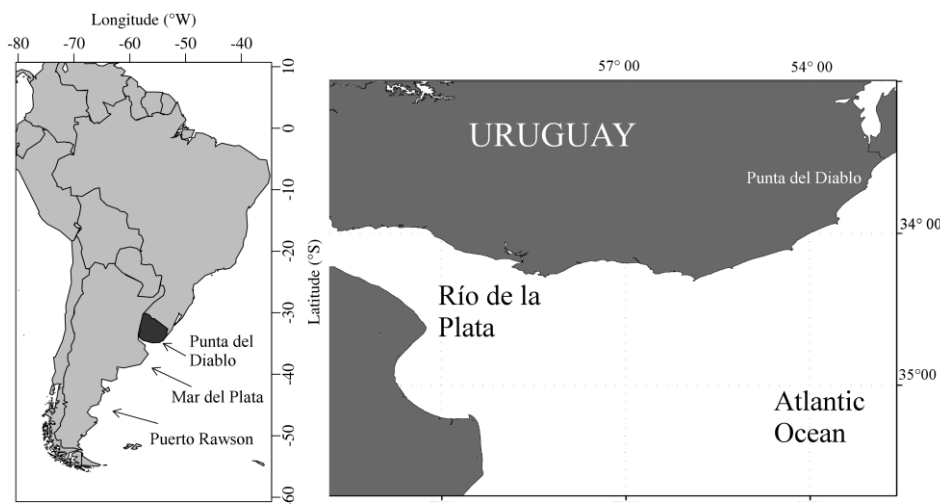


Figure 1. A) Southwestern Atlantic Ocean and locations where population descriptors of *Pleoticus muelleri* were compared. B) Detailed map of Uruguayan coast showing Punta del Diablo-Uruguay.

Sampling and laboratory procedures

Shrimps were sampled onboard artisanal boats fortnightly in two consecutive fishing seasons from September 2005 to January 2006 and from September to November 2006 (austral spring-summer). The small boats (7-9 m length) operated in

a daily basis, with an outboard-engine (15-25 HP). The fishing gear was a bottom-trawl net 9 m wide, 1.2 m high, with a 30 mm tightened mesh in the opening and 25 mm mesh in the cod-end. The towing speed was 1.5 knots and the elapsed time was ca. 20 min (Segura *et al.* 2008). One to three

random tows were selected in each sampling date and random sub-samples were taken from the catch before the beginning of the discard process.

Shrimps were transported to the laboratory within the fishing day and sexed by recognizing secondary sexual characters following Pérez-Farfante (1977). In each shrimp, its cephalotoracic length (CL), was measured from the suborbital margin to the dorsal margin of the cephalotorax and total length (TL) was measured from the suborbital margin to the tip of the telson in a straighten way. Measurements were made to the nearest 0.05 mm with a caliper. Wet weight (WW) was recorded in the laboratory to the nearest 0.1 g with an OHAUS analogue scale. Male and female gonadal stages were assigned based on available descriptions of gonadal macroscopic developmental stages (Fenucci 1980, Boschi 1989, Diaz *et al.* 2003). Females were classified in four stages considering color and shape of the ovary, and if they present male's spermatophores impregnated in its ventral zone: stage I, immature (pale and not developed); stage II, mature (dark green and developed); stage III, impregnated (dark green ovary, fully developed, spermatophores impregnated in the ventral zone) and stage IV, spawned (dark ovary, reduced). Males were classified considering the presence and color of the terminal ampulae in three stages: I, immature (white terminal ampulae); II mature (green terminal ampulae) and IV, evacuated (without terminal ampulae).

Data analysis

CL was used to determine size differences and as the explanatory variable in Length-weight and CL vs TL regression because it is the most accurate measure in penaeid shrimps (Diaz *et al.* 2001). Shrimp's lengths (CL) were compared among sexes with the Mann-Whitney U test (Zar 1999). Parameters of the length-weight relationship were estimated using the linearized ($\log(\text{WW})=a+b \log(\text{CL})$) functional (reduced major axis) regression (Ricker 1973) for both sexes (Ricker, 1973). Slopes (b) were compared between sexes by means of confidence interval overlap (Ricker, 1973). LWR estimated for different populations of the shrimp were obtained from literature and compared to present estimations. Size at first maturity was estimated by two methods: i) logistic regression (Hosmer & Lemeshow 1989) and ii) as the breakpoint in the CL-TL regression (Somerton 1980, Lovet & Felder 1989, Diaz *et al.* 2001). Using the logistic approach, the size at 50% maturity (CL_{50}) was estimated as the length at which a randomly chosen specimen has a 50% chance of

being mature (Somerton 1980, Roa *et al.* 1999). CL was considered the explanatory variable and the gonad immature (Stage I) or gonad mature (stage II; III and IV) condition, coded as 0, 1 (binomial variable) was considered the response variable (Hosmer & Lemeshow 1989). CL and the maturity condition were fitted to a logistic function with the form:

$$P_{CL} = \frac{\exp(-\hat{\beta}_0 - \hat{\beta}_1 CL)}{[1 + \exp(-\hat{\beta}_0 - \hat{\beta}_1 CL)]} \quad (1)$$

where P_{CL} is the probability of a shrimp of being mature at a determinate cephalothorax length, $\hat{\beta}_0$ (intercept) and $\hat{\beta}_1$ (slope) are parameters estimated by maximum likelihood in R statistical package (R Development Core Team 2010). CL_{50} was calculated as:

$$CL_{50} = \frac{-\hat{\beta}_0}{\hat{\beta}_1} \quad (2)$$

The analytical $100(1-\alpha)$ % confidence interval was defined by:

$$\frac{1}{\hat{\beta}_1} (-\hat{\beta}_0 \pm z_{\frac{\alpha}{2}} v(P_{CL50})) \quad (3)$$

where $z_{\alpha/2}$ is a quantile of the normal distribution and v is the square root of the analytical variance of the logit link function (Roa *et al.* 1999).

Breakpoint analysis detects size-dependent changes in growth rates in the CL-TL regression (Somerton 1980, Lovet & Felder 1989). This method subdivides repetitively the data into two CL delimited subsets at a hypothesized transition point, TP ($CL_I < TP$ and $CL_{II} > TP$). A separate regression function was calculated for each of the two subsets after each reallocation of the T_p (T_p step=1 mm CL). The size at maturity was chosen as the CL in which the combination of regressions fit the data better. The best fit was chosen as to minimize the sum of the squared residuals (SSR). The fitting of the two-stage model was compared with a model based on only one stage using the F-statistic with 2 and N-P degrees of freedom:

$$F = \frac{[(SSR_I - SSR_2)2]}{\left[\frac{SSR_2}{(N - P)} \right]} \quad (4)$$

where P is the number of parameters; N is the number of observations and SSR_1 and SSR_2 are the sum of the residual squares from the one and two-stage models respectively.

Growth parameters of *P. muelleri* were estimated using the ELEFAN I routine in FISAT II software (Gayanilo & Pauly 1997). Asymptotic cephalothorax length (CL_∞) and 95% confidence interval (CI) were obtained using the Powell-Wetherall method (Wetherall 1986). We fitted the seasonalized von Bertalanffy growth function (VBGF) (Gayanilo & Pauly 1997) to our LFD as:

$$CL_t = CL_\infty \left(1 - e^{\left[-K(t-t_x) - \left(\frac{CK}{2\pi} \right) \sin(2\pi(t-WP)) \right]} \right) \quad (5)$$

where, CL_t is the cephalothorax length at age t (mm), CL_∞ is the asymptotic cephalothorax length (mm), K is the growth coefficient (year^{-1}), C is the amplitude of oscillations, t is age (year), t_x are the coordinates of a point through which the curve must pass and WP is the winter point, a period of the year when growth is slowest. ELEFAN I program estimates only two of the growth parameters (CL_∞ and K) thus we set the other parameters based on previous studies on shrimp growth, as follows: The amplitude of oscillations (C) was set to 1 based on Pauly's empirical relationship with the yearly difference on water temperature (Pauly 1987) which in the zone is $\Delta T > 12^\circ\text{C}$ (A. Segura unpublished data). The winter point (WP) was fixed at 0.5, coinciding with the time of minimum temperature in the zone.

To select the best fitted VBGF we performed the ELEFAN I response surface analysis routine which displays the goodness of fit of a combination of parameters (CL_∞ and K). The selection of the best parameters was based on two conditions: 1) highest goodness of fit index (Rn) and 2) CL_∞ within the 95% CI of the estimation provided by the maximum length estimate method in FISAT II.

The goodness of fit index (Rn) is defined by

$$Rn = 10^{\text{ESP/ASP}/10} \quad (6)$$

where the ASP ("Available Sum of Peaks") is computed by adding the "best" values of the available "peaks" and the ESP ("Explained Sum of Peaks") is computed by summing all the peaks and troughs "hit" by the above growth curve.

The best estimates of CL_∞ and K were used for comparison of growth performance index ϕ'

between sexes using the equation (Pauly and Munro 1984):

$$\phi' = \log K + 2 \times \log CL_\infty \quad (7)$$

Results

Fishing season varies among years, but generally lasts from October to December. From January to September the shrimp abundance is null or scarce. For example, no shrimps were captured in trawls made in September 2005 or January 2006. At the end of August 2006 fishermen captured a few small shrimps and there were no more catches until the end of September.

Within the study period, a total of 1842 shrimps were sexed and measured from which 1016 were females and 826 males. Shrimps length ranged from 12.30 to 46.05 mm CL in females and from 11.65 to 34.70 mm CL in males. The length frequency distribution (LFD) showed peaks for females and males at 28 mm and 22 mm CL respectively (Fig. 2A) with females being significant larger than males (Mann-Whitney U; $Z = -20.06$; $P < 0.001$). The Length Weight relationship (LWR) presented sexual dimorphism. The slope of the regression (average \pm confidence interval) did not overlap between females ($b = 2.771 \pm 0.0190$) and males ($b = 2.999 \pm 0.0340$). Shrimps were heavier at a given length further south as indicated by the coefficients of the LWR (Table I). Size at first maturity CL_{50} estimated using logistic regression varied in relation to gender (Fig. 2B). Females (CL_{50} [CI] = 32.28 [31.69-32.87] mm) attained maturity at a larger size than males (CL_{50} [CI] = 25.08 [24.60-25.55] mm).

The linear relationship CL-TL for both sexes was better fitted by a two stages model than one stage model ($F_{2,418} = 15.52$; $P < 0.001$ for females and $F_{2,385} = 23.86$; $P < 0.001$ for males) (Fig. 3A,B). The size at maturity defined by estimated break points were 32 and 26 mm CL for females and males respectively (Fig. 3C, D).

The asymptotic length estimated by the Powell-Wetherall method was 48.38 for females and 31.8 for males. Maximum length routine (CL_∞ - 95% CI) estimated 51.61 mm (46.45-56.77) for females and 34.10 mm (31.44-36.75) for males. Parameters of the VBGF showed a bigger asymptotic length for females than males, and a smaller growth constant. The growth performance index was higher for females than males (Table II).

Table I. Parameters of the power function ($WW=a*CL^b$) estimated using functional regression (FR) for *Pleoticus muelleri* in its distribution range.* Denotes estimations made on the 0.5 quantile of the distributions, thus are not directly comparable to FR.

STUDY SITE (LATITUDE)	SEX	a	b	N	CL RANGE (mm)	R ²	STUDY
Punta del Diablo	FEMALES	0.00093	2.77	729	14.90-46.05	0.97	Present study
Uruguay (33° S)	MALES	0.00051	3.00	574	11.65-34.70	0.93	
Mar del Plata	FEMALES	0.00190	2.63			0.93	Diaz <i>et al.</i> (2003)
Argentina (38° S)	MALES	0.00200	2.64			0.89	
Rawson	FEMALES	0.00510	2.41			0.95	Mendia & Ruiz (2002)
Argentina (48° S)	MALES	0.00500	2.41			0.95	
Argentina (48° S)	FEMALES*	0.00137	2.76		10- >60	-	De la Garza (2003)
	MALES*	0.00069	2.98		10- >45	-	

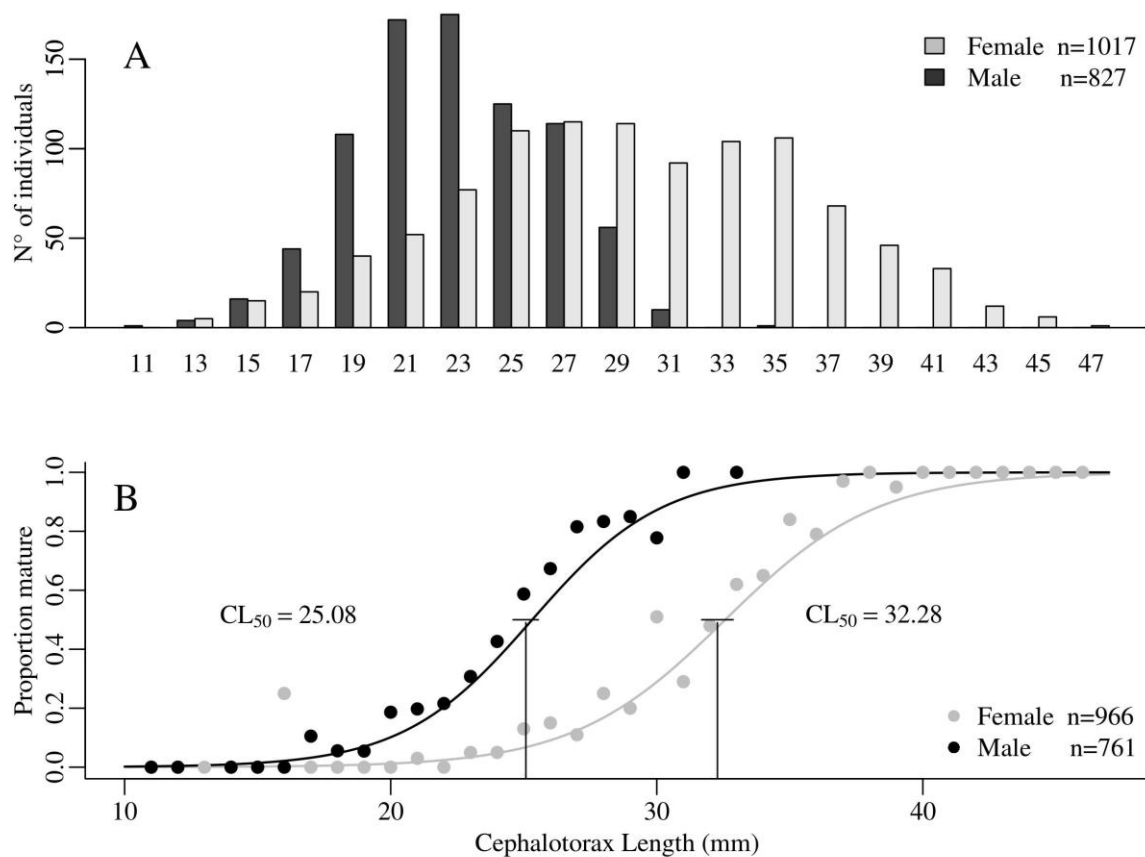


Figure 2. A) Length frequency distribution (LFD) of *Pleoticus muelleri* captured off Punta del Diablo-Uruguay 2005-2006. B) Maturity data as the percentage of mature individuals per size class (closed symbols) and maximum likelihood fitted functions for females and males of red shrimp (*P. muelleri*). Horizontal lines represent the 95% analytical confidence interval for size at 50% sexual maturity (CL_{50}).

Discussion

This study estimated for the first time the size at maturity and growth parameters for individuals of *Pleoticus muelleri* captured in the Uruguayan Atlantic coast. Results showed that the red shrimp have different reproductive tactics and growth rates along its distribution range which suggest plasticity in their life history traits. The breakpoint analysis of size at maturity proved to be a

useful method to estimate size at maturity in this species. This method should be used in routine fishery evaluations as do not require expensive histological analysis to determine sexual maturity or subjective classifications of gonadal stages. However, the use of several techniques to estimate sexual maturity is encouraged in order to avoid biases caused by a particular methodology.

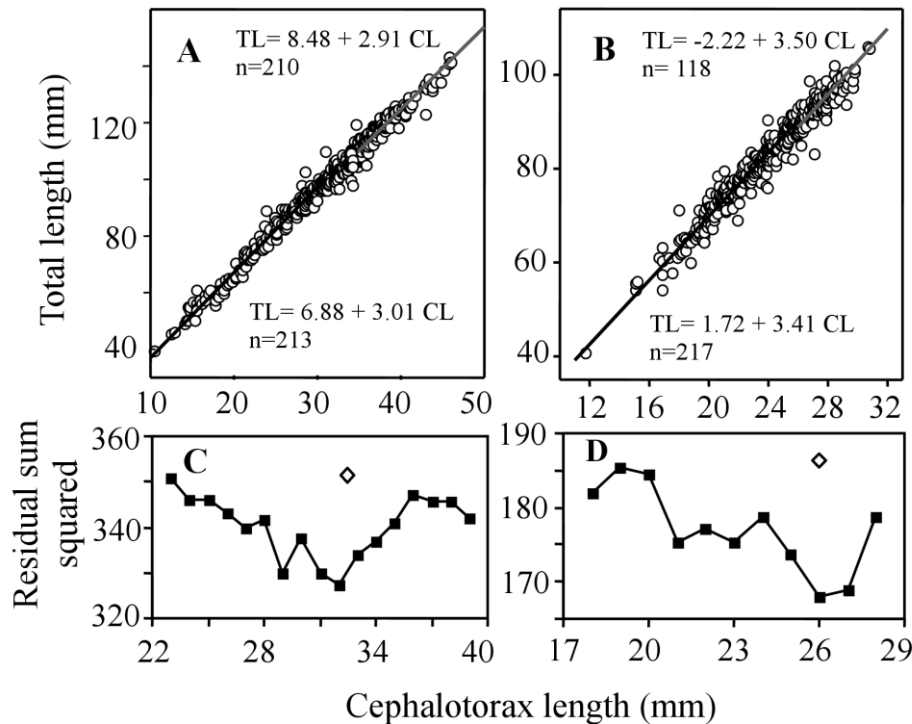


Figure 3. *Pleoticus muelleri* piecewise cephalothorax length-total length (CL-TL) relationship with a transition point at 32 and 26 mm CL –A) for females and –B) males. CL vs. Residual sum squared (RSS) of the two-stages piecewise linear regression (black squares) and the RSS of the one-stage linear regression (open diamond) for –C) females and –D) males. Note a different scale in CL between females and males.

The fact that juveniles and adult shrimps were found in coastal saline waters is in accordance to previous reports for this species (Boschi 1989) and differs from other penaeid shrimps, such as *Farfantepenaeus paulensis*, which for example utilizes Uruguayan coastal lagoons as nursery grounds (García & Le Reste 1986, Santana & Fabiano 2006). Length frequency distribution showed an absence of the largest sizes (CL>44 mm). Biggest size classes probably migrate to deeper waters as it occurs in Patagonia (Boschi 1989) and cannot be captured by this artisanal fleet, because of

their operational limitations. An alternative explanation is that the species does not reach larger sizes in Uruguayan coast because of higher average temperature in Uruguayan coast. These two alternatives have to be explored further.

Females' reaching larger sizes than males is common in shrimps and had been mentioned for *P. muelleri* in Patagonian waters (Boschi 1989). This fact is related to reproductive fitness, as bigger females produce more eggs than smaller ones (Macchi *et al.* 1998).

The CL-WW relationships for this

population estimated using Functional (model II) regression, showed that the weight of shrimps at a given length tends to increase the farther south they are located (Table I). This pattern was evident in a size comparison between Argentina and Brazil of populations of *Artemesia longinaris* a co-occurrent

species (Castilho *et al.* 2007). This latitudinal effect is probably related to the effect of increasingly colder water to the south, which is known to increase maximum individual size in crustaceans (Hartnoll 1982).

Table II. Parameter estimation of the ELEFAN I and Power wetherall (PW) method analysis of Length frequency distribution for females and males of *Pleoticus muelleri* (L_{∞} , asymptote length (mm); K, growth coefficient (yr^{-1}); ϕ' , growth performance index; Rn, goodness of fit index).

SEX	PW- L_{∞}	L_{∞}	K (year^{-1})	ϕ'	Rn
FEMALE	48.4	53.0	1.36	3.58	0.220
MALE	35.5	35.5	1.51	3.28	0.506

Size at maturity CL_{50} estimated using logistic regression and the breakpoint analysis yielded similar results, extending thus the applicability of this method for this species. In females, both methods yield exactly the same estimate, so the value could be considered an accurate approach to the size at maturity for the uruguayan coast. Our estimates are similar to previous estimations for females in Argentinean waters (Boschi 1989) and slightly below a recent estimate calculated using CL-TL breakpoint analysis (33 mm CL; De La Garza 2003). The allometry found in female's CL-TL relationship at sexual maturity is related to gonadal development which occurs mostly in the cephalothorax and had been registered in this species (De la Garza 2003) and in other penaeids shrimps (Hartnoll 1982, Diaz *et al.* 2001). However, the break point analysis and logistic estimation were slightly different for males (*i.e.*, 1 mm CL difference), but for management purposes, the difference could be considered negligible. Our proposed size at maturity is within the range proposed for male shrimps in Argentinean waters, which spanned from 24 to 28 mm CL according to Boschi (1989) and close to the figure of 26 mm CL estimated by De La Garza (2003). In spite of being an easily applicable field method, validation with logistic or histological techniques is recommended. Our results showed contrasting patterns in LWR and size at maturity in the latitudinal range (Table I) which precludes any statement about the presence of different population of *P. muelleri*. Complementary analysis using genetics or morphometrics are needed in order to determine the presence of different populations in its latitudinal range (Begg & Waldman 1999).

The Seasonal von Bertalanffy growth models fitted adequately as shown by their goodness

of fit (Table II). There were clear differences among females and males, with the latter showing a better model fit. The growth coefficients ($K= 1.36 \text{ y}^{-1}$ in females and 1.51 y^{-1} in males), were close to the figures reported for Argentinean (47° S) shrimps captured in 1998 ($K= 1.39$ and 1.42 y^{-1} for females and males respectively; Fischbach & Bertuche 1999) and slightly superior than estimates made for shrimps caught in 2004-2006 ($K= 1.05$ and 1.11 y^{-1} for females and males respectively; De La Garza 2006). In terms of growth performance index (ϕ') our results were well within previous calculations made in the aforementioned studies in females and close but slightly below in males. The similar patterns in growth of Uruguayan shrimps as compared to estimates captured in Argentina in 1998 could be related to positive anomalies in water temperatures in the 1998 period (De La Garza 2006), but this fact has to be explored further. It would be straightforward to compare growth dynamics of this species in its full distributional range, including Brazilian waters, to evaluate the effect of temperature on *P. muelleri* growth.

Some shortcomings of the sampling design and statistical methodology to evaluate growth has to be noted. For example, the absence of shrimps in the zone in autumn and winter could bias our results. In these seasons, the low number of sampled organisms impedes a correct distinction among modal classes. This fact diminishes the explained variance of the VBGF model, as different modes or cohorts can present different growth rates. Despite the estimation of growth parameters were done using data from two consecutive years, variability in oceanographic conditions, such as temperature, could modify shrimp growth parameters between seasons (Pauly 1987) and thus increase uncertainty. Another relevant parameter to consider is the

amplitude of oscillation (C), which was set as 1 according to the empirical relation with temperature variability proposed by Pauly (1987). In this study, no formal evaluation on the effect on the fit of this parameter was conducted, and previous studies for this species in similar temperature ranges suggest that the growth does not stop completely ($C < 1$) as assumed here (De La Garza 2006). However, in general, present estimates are within the range of reported values in penaeid shrimp species (0.39–1.6;

Pauly *et al.* 1984; Garcia & Le Reste 1986) and the sexual differences in growth, characterized by males with lower CL_{∞} and higher K than females (García & Le Reste 1986) were captured. Thus, we believe present estimates can be used as a first approximation to describe shrimp growth for Uruguayan coast. An extension of the sampled zone in Uruguayan waters, in order to evaluate the migration hypothesis and to follow the cohorts throughout their life cycle is recommended.

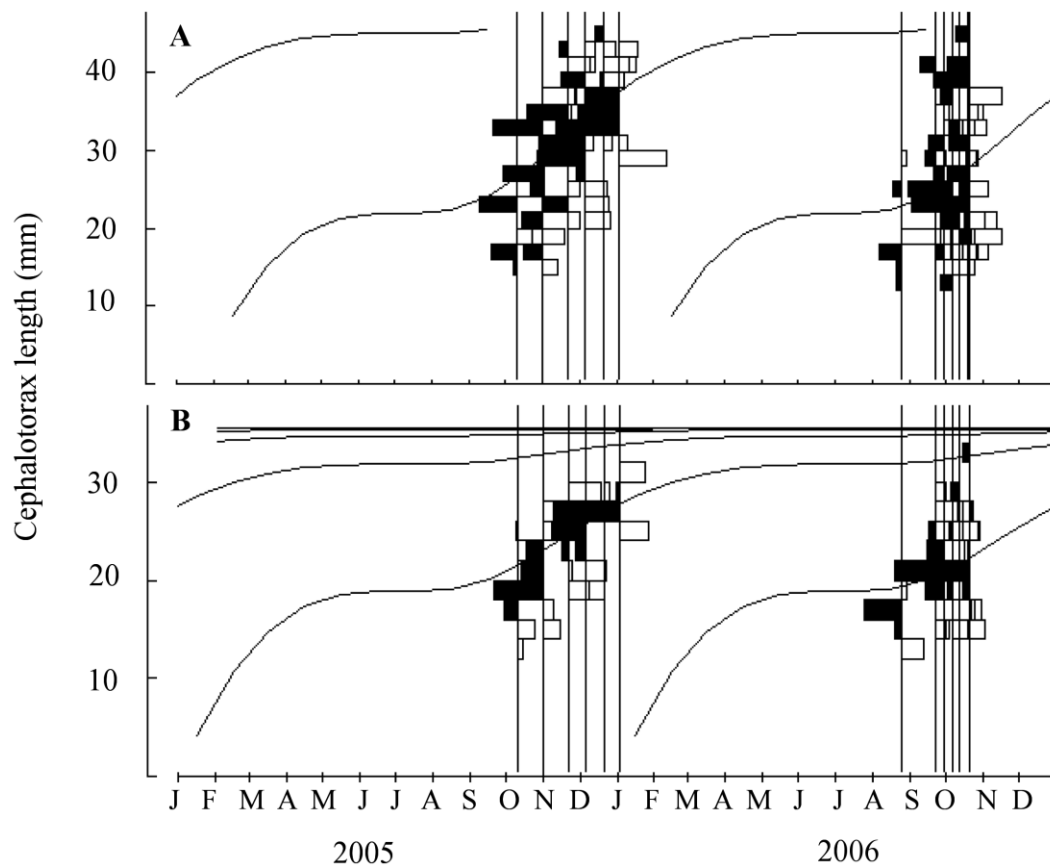


Figure 4. Seasonalized von Bertalanffy growth curves of *Pleoticus muelleri* in 2005 and 2006 as superimposed on the restructured length-frequency histogram in A) females and B) males. Note the different scale in the y axis.

As a final remark concerning management, it is worth to note that the shrimp relatively rapid growth and its migration out of the operational limits of the artisanal fleet probably allow a great fraction of the population to escape from trawling. Thus, a high impact on shrimp abundance is not expected. Thus, a spatial or temporal closure of this artisanal fishery doesn't seem to be an effective management action for shrimp or ecosystem-based preservation. Ecosystem-based approaches, considering the by-catch of this fishery are needed in order to determine its impact on the local demersal and benthic communities. The adequate knowledge of this

fishery dynamics and its ecosystem impacts are highly relevant as the zone was recently declared as the first Marine Protected Area in Uruguay.

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