Research Article

Analysis of the relationship between relative abundance of mature, impregnated females of *Pleoticus muelleri* (Bate, 1888) (Crustacea, Decapoda) and environmental variables through statistical models

Mónica Fernández[1], Daniel Hernández[1] & Ana Roux[1]
[1]Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP)
Paseo Victoria Ocampo 1, B7602HSA, Mar del Plata, Argentina

ABSTRACT. The relationship between the relative abundance of mature and impregnated females of the Argentine red shrimp *Pleoticus muelleri* (Bate 1888) and environmental variables was analyzed using statistical methods. Analyzed data came from the research cruises of the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP) carried out during January 2000, 2001, 2005, and 2007; March 2006; and November 2004, 2005, and 2006 in San Jorge Gulf (Argentina). The biological variables considered were the relative abundances of mature and impregnated female shrimp, whereas the environmental variables corresponded to depth, bottom water temperature and salinity, and the difference between surface and bottom water temperature and salinity. Generalized additive models were used as an exploratory tool for the numerical data and the general linear models as a confirmatory tool. The results showed that the distributions and abundances of mature and impregnated females were related to the bottom water temperature and salinity and to depth. The relationship increased along with temperature; with salinity, however, it decreased for mature females and increased for impregnated females. An optimal depth range was evidenced, where the largest concentrations of these individuals were located.

Keywords: *Pleoticus muelleri*, females, maturity, abundance, environmental conditions, GLM, GAM, southwestern Atlantic, Argentina.

Análisis de la relación entre la abundancia relativa de las hembras maduras e impregnadas de *Pleoticus muelleri* (Bate, 1888) (Crustacea, Decapoda) y las variables ambientales aplicando modelos estadísticos

RESUMEN. Se presenta el análisis de la relación entre la abundancia relativa de las hembras maduras e impregnadas del langostino *Pleoticus muelleri* (Bate, 1888) y las variables ambientales, mediante la aplicación de modelos estadísticos. Los datos analizados provienen de las campañas de investigación del Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP) realizadas en enero de 2000, 2001, 2005 y 2007, marzo de 2006 y noviembre de 2004, 2005 y 2006 en el Golfo San Jorge (Argentina). Se consideraron las variables biológicas: abundancia relativa de hembras maduras y de hembras impregnadas de langostino y las variables ambientales: profundidad, temperatura y salinidad del agua de fondo así como, la diferencia de temperatura y de salinidad entre el agua de superficie y de fondo. Para el tratamiento numérico de los datos se aplicaron Modelos Aditivos Generalizados como herramienta exploratoria y Modelos Lineales Generales como herramienta confirmatoria. Los resultados indican que la distribución y abundancia de las hembras maduras e impregnadas se relacionan con la temperatura y la salinidad del agua de fondo, y con la profundidad. Con la temperatura se destaca una relación creciente; mientras que con la salinidad, una relación decreciente con las hembras maduras y una relación creciente con las hembras impregnadas. Considerando la profundidad, se evidenció un rango óptimo donde se localizaron las mayores concentraciones de estos individuos.

Palabras clave: *Pleoticus muelleri*, hembras, madurez, abundancia, condiciones ambientales, GLM, GAM, Atlántico sudoccidental, Argentina.

Corresponding author: Mónica Fernández (monica-fernandez@inidep.edu.ar)

INTRODUCTION

The distribution of the Argentine red shrimp *Pleoticus muelleri* (Bate, 1888) (Decapoda, Solenoceridae) (FAO Code 2282900601, Garibaldi & Busilacchi, 2002) is restricted to the Western Atlantic, from Río de Janeiro (23ºS), Brazil to Santa Cruz (50ºS), Patagonia, Argentina. This species remains in the marine environment throughout its life cycle (Boschi, 1997).

The *P. muelleri* fishery is one of the most important in Argentina. It occurs mainly in the patagonic sector comprised between 43º and 47ºS. The fishery started to be exploited at the beginning of the '80 when 2,616 ton were landed reaching 36,822 ton in 2000. That year the exports were close to U$S 250 millons. In year 2001 the declared landings reached to a historic record of 78,797 ton (SAGPyA, 2001). In Brazil the fishery is mainly developed in San Paulo coast. During 1999-2005, 54.65 ton were caught with a peak of 34.06 ton in 2001 and a successive decline in others years (Castilho *et al.*, 2008a). In Uruguay the species is targeted by the artisanal fleet operating and the highest fishing effort is located in Punta Del Diablo. The total shrimp-catch per fishing season in 2005 and 2006 was 12 ton (Segura *et al.*, 2008).

In Argentina, Bertuche *et al*. (2000a, 2005) indicate that this natural resource shows biological characteristics that made very difficult the management of the fishery. They are: short life cycle, a high and variable grown rate and a high reproductive potential. The short life cycle, determines that the available biomass for fishing replaces itself each fishing season. The annual recruitment defines the abundance of the resource. The success of the recruitment depends of two factors: the spawning biomass concentrates in the appropriated time and space and the benevolence of the environmental context where the first life cycles stadia are developed. Considering the above mentioned concepts arise the need of face up studies on the reproductive activity and its relationships with the environmental factors which regulate it and lets generate tools for fishery management.

The Argentine red shrimp reproductive activity occurs during spring and summer and shows its maximum intensity between December and March. Reproduction takes place all along the patagonic littoral forming reproductive nuclei concentrated in coastal zones; the main spawning area is comprised between 42º and 47ºS where different sectors as regars start, duration and intensity of the reproductive process are distinguished. These sectors are: the south littoral of Rawson (43º20'S-44º20'S and 64º00'W and the coast) and the San Jorge Gulf areas limited by the coasts and the 46ºS (north and south sectors of the gulf). In the north area of San Jorge Gulf the reproductive season starts in August and continues throughout summer until March or April. Individuals in advanced maturation stage are observed in September. In the southern zone the period embraces from September through April. Individuals in advanced maturation stage are observed in November. In the south littoral of Rawson concentrations of great mangnitude are detected in October, November and December. Impregnated females -mature females with the maximum degree of ovaric development and added spermathofore- reach their abundance peak during November in the Rawson littoral, in December in the north of San Jorge Gulf and during January in the southern area. (Macchi *et al*., 1998; Ruiz & Mendia, 2008; Fernández *et al.*, 2009).

The species *P. muelleri* all along its distributional area presents different reproductive behaviours, being the reproduction continuous in tropics and seasonal in higher latitudes (Castilho *et al*., 2008a).

It has to be mentioned that different studies on the relationship between the development of the resource and environmental variables in the argentine red shrimp fishery applying statistical models were carried out by Bertuche *et al*. (2000b) and Fernández *et al.* (2007).

Bertuche *et al.* (2000b), applying the Multiple Regression Model observed the existence of a statistically significant relation among the fluctuation of Argentine red shrimp abundance in the San Jorge Gulf, the fishing effort applied and two representative variables of changes in the climate conditions (temperature anomalies in surface waters in San Jorge Gulf and Peruvian coasts). Fernández *et al.* (2007), using the Canonical Correspondence Analysis looked into the shrimp concentration distribution in the south of the San Jorge Gulf in winter 2003 and its relation to the physical and chemical characteristics of surface sedi-ments and bottom waters. The mentioned authors found links among juvenile and adult shrimp and depth and total organic carbon in sediments.

Researches developed by Ye *et al*. (1999), Hass *et al*. (2001), Costa *et al*. (2004) and Castilho *et al.* (2008b), can be mentioned as examples of the use of statistical models in the study of the relationship among other prawn and shrimp fisheries and environmental variables. Ye *et al*. (1999) carried out an analysis of the environmental preferences of *Penaeus semisulcatus*, *Metapenaeus affinis* and *Penaeus stylifera* in Kuwait using the Accumulated Univaried and Bivaried Distribution Analysis and they found that each species showed different preferences as regards temperature, salinity and depth. Depth was the variable that most influenced the distribution of these penaeids species. Hass *et al.* (2001) modeled the *Penaeus aztecus* abundance associated to biological and environmental factors applying Multiple Regression, Bayesian Models and Generalized Additive Models. Only temperature and salinity variables showed a positive correlation with the abundance.

Costa *et al.* (2004) studied the ecological distribution of *Pleoticus muelleri* from January 1998 through December 1999 in the region of Ubatuba, São Paulo, Brazil. They observed that the numbers of *P. muelleri* were positively correlated with periods of cooler temperatures. Castilho *et al.* (2008b) in their work about the relationship between environmental variation and species abundance of shrimp community (Crustacea: Decapoda, Penaeoidea) in south-eastern Brazil using a Canonical Correlation Analysis found a positive relationship between abundance of *P. muelleri* and depth and an inverse association with bottom temperature. Although, temperature and depth were strongly associated with the abundance of X*iphopenaeus kroyeri*.

In this study two moments of the reproductive period of argentine red shrimp in San Jorge Gulf (spring and summer) are analyzed. Generalized Additive Models combined with General Linear Models are applied to determine the relation among relative abundance of mature and impregnated female shrimp and environmental variables as well as to identify the variables that allow explain part of the spatial variability of reproductive females abundance values.

MATERIALS AND METHODS

Samplings and data were obtained from hauls performed during Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP) research cruises OB-01/00 (January 2000), OB-01/01 (January 2001), OB-09/04 (November 2004), OB-01/05 (January 2005), OB-10/05 (November 2005), OB-01/06 (March 2006), OB-06/06 (November 2006) and OB-02/07 (January 2007). Cruises were carried out on board of RV “Capitán Oca Balda” in the area comprised between 43º20´-47º00´S and 64º´W and the coast (Fig. 1).

The biological variables considered were mature females (MF) and impregnated females (IF) relative abundance expressed in thousand of ind nm^{-2}. The environmental variables considered were depth in metres (D), bottom water temperature in ºC (BWT), bottom water salinity in psu (BWS), temperature difference (ΔT) and salinity difference (ΔS) between surface and bottom waters. The data were measured with a conductivity-temperature-depth probe SBE (Sea-Bird Electronic, I Model XIX).

The statistical analysis (Zar, 1996; McCullagh & Nelder, 1989; Hastie & Tibshirani, 1990) was performed using the statistical program Statistica, version 6.0 (Statistica Software 1988). For the same months, the comparison of environmental variables among years was made using Kruskal Wallis test (Zar, 1996).

For the statistic treatment of data January 2001 and November 2005 were not considered. January 2001 presented 17.39% of non null values mature females and 0% of non null values impregnated females. November 2005 presented 19.30% and 1.75% of non null values mature females and impregnated females, respectively. Besides, in January 2000 the “ΔS” variable was eliminated for its low variability. In January 2000 and 2005, March 2006 and January 2007 “ΔT” was eliminated for its high correlation with the BWT.

The relationship among mature females and impregnated females abundance with environmental variables depth , bottom water temperature, bottom water salinity, temperature difference and salinity difference were analyzed considering an exploratory focus where GAM were applied (Yee & Mitchell, 1991; O'Brien *et al*., 1996; Xiang, 2001; Venables & Dichmont, 2004). The GAM considered (link = identity, distribution = normal) was:

$$\ln(y + 1) = \beta_0 + f_1(D) + f_2(BWT) + f_3(BWS) + f_4(\Delta T) + f_5(\Delta S) + \varepsilon$$

being:

γ: relative abundance of mature and of impregnated females,

f_j: a non parametric function to be determined, defined by means of smoothing from cubic splines of the relation between the partial residual and each environmental variable (scatterplot smother),

ε: error term.

In those cases in which several years and different sectors of the gulf were included in the data, the categorical variables Year and Sector (north and south of San Jorge Gulf) were introduced in the model.

Once the f_j function determined, a GLM (General Lineal Model) was considered (McCullagh & Nelder, 1989) in order to confirm the statistical significance of nonlinear components, quadratic or cubic (depending on the type of nonlinearity observed in the Scatterplot Smoths shown by the GAM) in the relationship of the

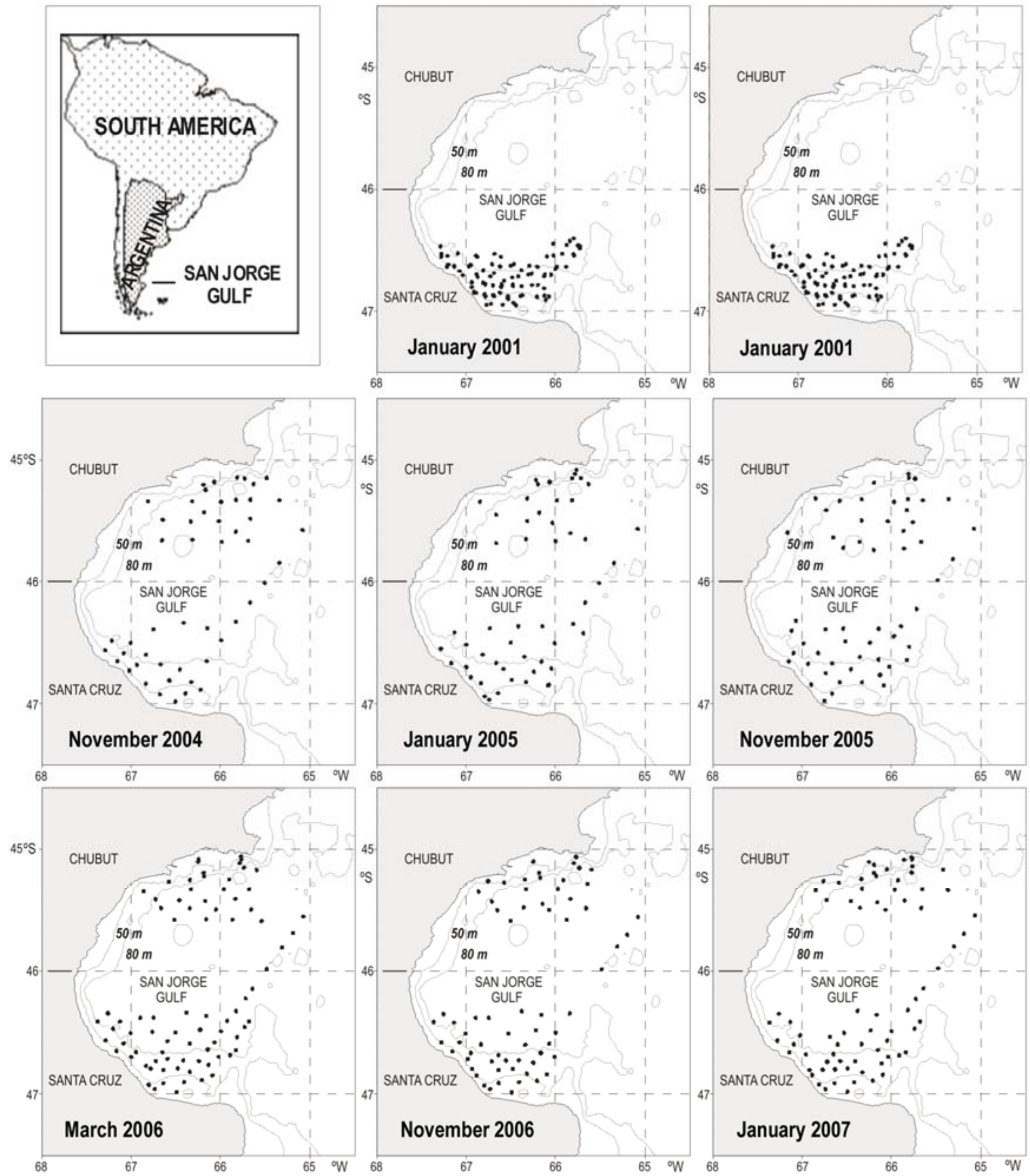

Figure 1. Geographic location of hauls of research cruises carried out during January 2000 and 2001, November 2004, January and November 2005, March and November 2006 and January 2007 in the San Jorge Gulf.

Figura 1. Ubicación geográfica de los lances de las campañas de investigación efectuadas en enero 2000 y 2001, noviembre 2004, enero y noviembre 2005, marzo y noviembre 2006 y enero 2007 en el golfo San Jorge.

abundances with environmental variables. The Akaike Information Criterion was used as a tool for model selection. Those variables not detected in GAM as nonlinear components in their relationship with abundances were incorporated as lineal form in the GLM, in the procedure of model selection. This fact allowed to determine the environmental variables significantly correlated with abundance and evaluate the existence of nonlinear components in the relation of abundance to environmental variables.

With the procedure developed a simple description of the relation among abundance and environmental variables was obtained. For this a model that considers lineal and non lineal additive components was built. It explained a significant percentage of the variance. Possible interaction terms among environmental variables were not considered due to: (1) the difficulty to understand the effect of such terms and (2) consider the objective of obtaining a simple and satisfactory description of the system analyzed.

The possible spatial correlation among the GAM residuals was calculated considering experimental semi-variograms. For the building of them, the following criteria were applied: (1) to consider distances lesser than or equal to half the maximum distance among sampling stations and (2) to be number of pairs of points in each interval more than 50 (Journel & Huijbregts, 1978).

RESULTS

The descriptive statistic of the environmental variables during January 2000, 2001, 2005, 2007, March 2006 and November 2004, 2005 and 2006 is presented in Table 1.

During January 2000 and 2001 the seasonal statistical analysis indicated highly significant differences ($P < 0.01$) considering the bottom water temperature variable. In January 2000 the average value was 11.57ºC, whereas in January 2001 was 9.56ºC. In the same period, the seasonal statistical analysis indicated highly significant differences ($P < 0.01$) considering the bottom water salinity variable. The average value was 33.43 psu in January 2005, whereas in January 2007 was 33.30 psu.

During November 2004, 2005 and 2006 the seasonal statistical analysis indicated highly significant differences ($P < 0.01$) considering bottom water temperature and salinity variables. Taking on account the average value, the maximum value of temperature was registered in November 2004 and the minimum in November 2005. The maximum value of salinity was observed in November 2005 and the minimum in November 2006.

Application of the Generalized Additive Models and the General Lineal Models

Mature females

The most remarkable nonlinear components that GAM allowed to detect are shown in Table 2. The components were expressed as polynomial of degree 2 or 3 in the corresponding environmental variable. The variables that were entered in the procedure of model selection for each period considered and the variables that were selected with this procedure are shown in Table 3. In all periods, the nonlinear components that were manifested in GAM were confirmed in GLM by the Akaike Information Criterion (Table 3).

Normal plots and the relationship among predictive and observed values for each analyzed period are shown in Figure 2, considering the obtained results from GAM and GLM. The percentages of explained variance per model are also indicated. In the case of GAM all the analyzed environmental variables were entered into the model. In the case of GLM only the selected variables by the procedure of model selection (Table 3) were considered.

Normal plots were satisfactory in all cases; the graphic corresponding to March 2006 showed a greater discrepancy probably due to the large proportion of null abundance values (51.9%).

Figure 3 shows the relationship among abundance (expressed as partial residues when eliminating from the abundance value the effect of other environmental variables that were not presented in the graph) and the considered environmental variables. The graphs show the pure effect that the environmental variables have on abundance values. The considered graphs correspond to the results obtained with GAM; only the graphs corresponding to the selected variables by the procedure of model selection are shown.

The obtained results allowed to observe (Fig. 3) that in January 2000, 2005 and 2007 and March 2006 the distribution of mature female abundance values was related to depth and bottom water temperature and that in November 2004 and 2006 was consistent with depth and bottom water salinity.

As regards the relationship among abundance values and the depth variable in January 2000, 2005 and 2007, the highest values were registered between 50-70 m approximately. When bottom water temperature was considered abundance values raised as temperature values increased. According to the graphs, there is less definition of relationship in January 2005 and 2007 compared to January 2000.

In March 2006 a growing relationship among abundance values distribution of mature females and depth and bottom water temperature was observed; abundance values raised as depth and temperature increased. In November 2004 and 2006 a decreasing relation of abundance values of mature females to depth and bottom water salinity was detected.

Impregnated females

The most remarkable nonlinear components that GAM allowed to detect are shown in Table 2. The components were expressed as polynomial of degree 2 or 3 in the corresponding environmental variables.

Table 1. Descriptive statistic of the environmental variables. January 2000 and 2001, January 2005 and 2007, March 2006 and November 2004, 2005 and 2006. N: number of hauls.

Tabla 1. Estadística descriptiva de las variables ambientales. enero 2000 y 2001, enero 2005 y 2007, marzo 2006 y noviembre 2004, 2005 y 2006. N: número de lances.

Environmental variables		Year	N	Mean	Standard deviation	Minimum value	Maximum value
Depth (m) (D)		2000	40	65.125	12.712	39.000	82.000
	J	2001	23	71.043	13.871	34.000	90.000
Bottom water temperature (ºC) (BWT)	A	2000	40	11.574	1.376	8.899	13.748
	N	2001	23	9.565	1.072	8.096	11.770
Difference of temperature (ºC) (ΔT)	U	2000	40	3.446	1.735	0.480	7.054
	A	2001	23	3.539	1.464	0.485	5.436
Bottom water salinity (psu) (BWS)	R	2000	40	33.493	0.082	33.267	33.618
	Y	2001	23	33.485	0.146	33.158	33.664
Difference of salinity (psu) (ΔS)		2000	40	0.067	0.142	-0.162	0.493
		2001	23	-0.139	0.147	-0.359	0.268
Depth (m) (D)		2005	53	75.170	15.225	31.000	96.000
	J	2007	75	72.533	16.691	25.000	100.000
Bottom water temperature (ºC) (BWT)	A	2005	53	10.646	2.014	8.155	15.335
	N	2007	75	10.558	1.523	8.737	14.593
Difference of temperature (ºC) (ΔT)	U	2005	53	4.515	2.459	0.139	8.034
	A	2007	75	4.665	1.882	0.021	7.258
Bottom water salinity (psu) (BWS)	R	2005	53	33.429	0.097	33.180	33.780
	Y	2007	75	33.303	0.074	33.124	33.492
Difference of salinity (psu) (ΔS)		2005	53	0.079	0.122	-0.239	0.540
		2007	75	0.055	0.066	-0.148	0.226
Depth (m) (D)	M	2006	53	76.189	15.488	31.000	100.000
Bottom water temperature (ºC) (BWT)	A	2006	53	10.569	2.128	8.244	15.467
Difference of temperature (ºC) (ΔT)	R	2006	53	4.632	2.241	0.116	7.908
Bottom water salinity (psu) (BWS)	C	2006	53	33.388	0.188	33.046	34.049
Difference of salinity (psu) (ΔS)	H	2006	53	-0.140	0.162	-0.768	0.111
Depth (m) (D)		2004	50	77.420	15.553	23.000	94.000
		2005	58	79.569	13.593	32.000	99.000
		2006	71	73.915	16.481	26.000	100.000
Bottom water temperature (ºC) (BWT)	N	2004	52	9.288	0.967	8.033	11.888
	O	2005	70	8.720	0.795	7.660	11.020
	V	2006	84	9.171	0.619	8.174	11.200
Difference of temperature (ºC) (ΔT)	E	2004	50	3.714	1.591	0.130	6.074
	M	2005	58	2.773	1.537	-0.250	5.390
	B	2006	71	1.420	0.767	0.003	3.029
Bottom water salinity (psu) (BWS)	E	2004	52	33.390	0.141	33.007	33.968
	R	2005	70	33.426	0.223	32.846	34.257
		2006	84	33.296	0.086	33.017	33.417
Difference of salinity (psu) (ΔS)		2004	50	-0.030	0.165	-0.634	0.503
		2005	58	-0.098	0.208	-0.891	1.000
		2006	71	-0.049	0.085	-0.265	0.083

Table 2. Mature and impregnated females. More remarkable nonlinear components detected in GAM, associated to some of the environmental variables for each period. D: depth, BWT: bottom water temperature, BWS: bottom water salinity.

Tabla 2. Hembras maduras e impregnadas. Componentes no lineales destacables detectadas por el GAM, asociadas con alguna de las variables ambientales, para cada período. D: profundidad, BWT: temperatura de agua de fondo, BWS: salinidad de agua de fondo.

	Period	Remarkable nonlinear components detected in GAM
Mature females	January 2000	Polynomial degree 2 in D
	January 2005 and 2007	Polynomial degree 2 in D
	March 2006	Polynomial degree 3 in BWT
	November 2004 and 2006	Polynomial degree 3 in D
Impregnated females	January 2000	Polynomial degree 3 in BWS
	January 2005 and 2007	Polynomial degree 3 in D
	March 2006	Polynomial degree 2 in BWT

Table 3. Mature and impregnated females. Variables selected by the Akaike Information Criterion. Nonlinear components detected in GAM for some of the environmental variables are entered to the procedure. D: depth, BWT: bottom water temperature, BWS: bottom water salinity, ΔT: difference of temperature, ΔS: difference of salinity.

Tabla 3. Hembras maduras e impregnadas. Variables seleccionadas por el Criterio de Información de Akaike. Se ingresan al procedimiento las componentes no lineales detectadas por el GAM para alguna de las variables ambientales. D: profundidad, BWT: temperatura de agua de fondo, BWS: salinidad de agua de fondo, ΔT: diferencia de temperatura, ΔS: diferencia de salinidad.

	Period	Variables entered	Variables selected
Mature females	January 2000	D, D^2, BWT, BWS	D^2, BWT
	January 2005 and 2007	D, D^2, BWT, BWS, ΔS	D, D^2, BWT
	March 2006	D, BWT, BWT^2, BWT^3, BWS, ΔS	D, BWT, BWT^3
	November 2004 and 2006	D, D^2, D^3, BWT, BWS, ΔS	BWS, D, D^2, D^3
Impregnated females	January 2000	D, BWT, BWS, BWS^2, BWS^3	BWS^2, BWS^3
	January 2005 and 2007	D, D^2, D^3, BWT, BWS, ΔS	D, D^3, BWT
	March 2006	D, BWT, BWT^2, BWS, ΔS	D, BWT, BWT^2, BWS

The variables that were entered in the procedure of model selection for each period considered and the variables that were selected with this procedure are shown in Table 3. In all periods, the nonlinear components that were manifested in GAM were confirmed in GLM by Akaike Information Criterion (Table 3).

In Figure 4 normal plots and the relationship among predictive and observed values for each analyzed period are shown considering the obtained results from GAM and GLM. The percentages of explained variance per model are also indicated. With the same criterion used to analyze mature females all variables were entered into GAM. In the case of GLM only the selected variables by the procedure of model selection from Akaike Information Criterion (Table 3) were considered.

Normal plots were satisfactory in all cases; the graphic corresponding to January 2000 showed a greater discrepancy for GAM and GLM. The percentage of explained variance with the GAM for the three considered periods was satisfactory. The ones corresponding to the GLM was low in January 2000.

In Figure 5 the relationship among the abundance and considered environmental variables is shown. The considered graphs correspond to the results obtained with GAM; only the graphs corresponding to the selected variables by the procedure of model selection are shown.

In January 2000 the distribution of impregnated female abundance values was related to bottom water salinity while in January 2005 and 2007 to depth and bottom water temperature. In March 2006 it was linked to depth and bottom water temperature and salinity.

In January 2005 and 2007 when depth was considered the highest abundance values were registered between 50-70 m approximately. When bottom water temperature was taken into account abundance raised as temperature values increased. In

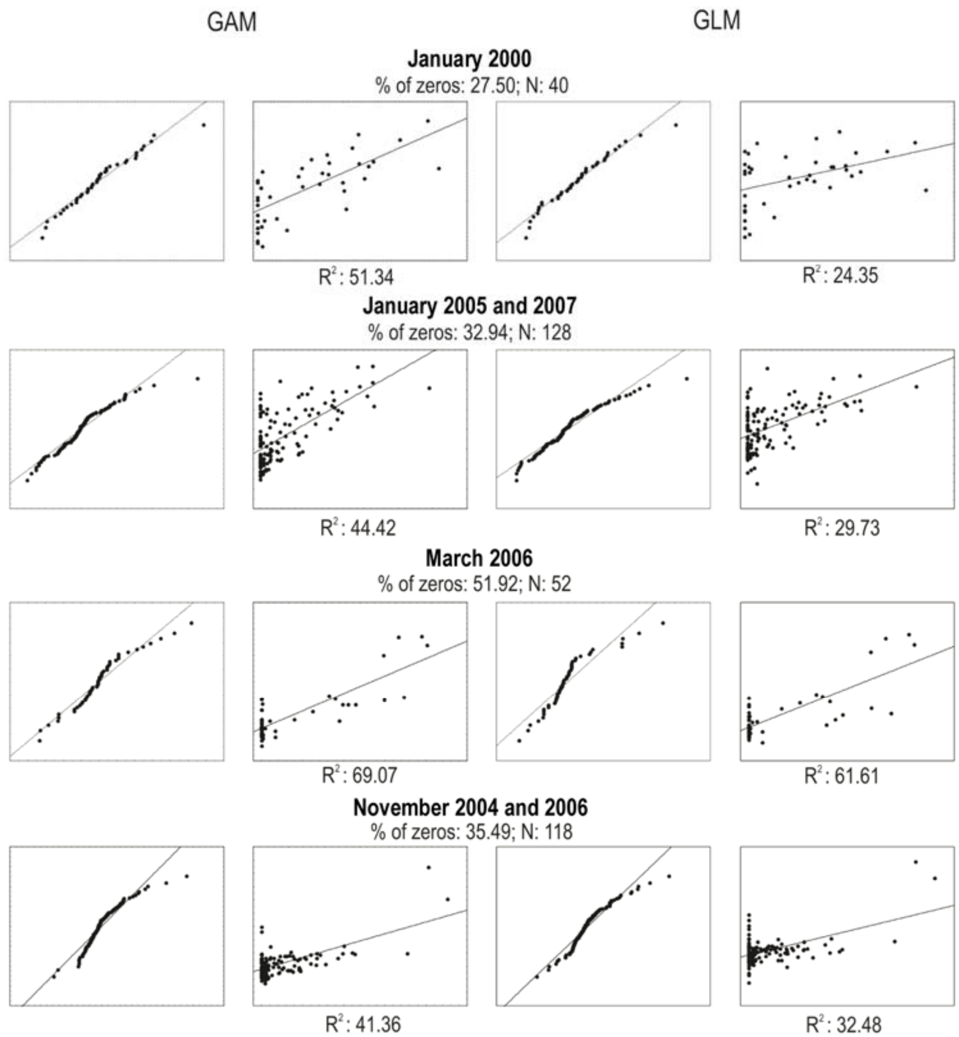

Figure 2. Mature females. Residual normal probability plot, relationship among predictive and observed values in each period. Explained variance percentage by the model R^2 and null data percentages in each period.

Figura 2. Hembras maduras. Diagramas de normalidad de los residuos y relación entre los valores predictivos y los valores observados, para cada período. Porcentaje de varianza explicada por el modelo R^2 y porcentaje de datos nulos en cada período.

both graphs the dispersion shown by the relation among variables is highlighted.

In March 2006 the relationship among considered variables and abundance values showed an increasing trend.

The semi-variograms corresponding to the residues obtained from the fit of the GAM, for mature females and impregnated females for each analyzed periods are shown in Figure 6. As can be observed no spatial correlation was detected.

DISCUSSION

The study of the relation among the relative abundance spatial distribution of mature and of impregnated shrimp females and environmental variables in San Jorge Gulf indicated that during the reproductive period the distribution and abundance of females were related to depth, bottom water temperature and bottom water salinity. Only in January 2000 a relationship with temperature difference was observed.

The importance of environmental factors such as water temperature, availability of food in the environment and the photoperiod for growth, ovarian development and maduration and beginning of spawning of aquatic and terrestrial crustaceans is well known and studied (Powers & Bliss, 1983; Alpuche *et al*., 2005). The importance of water temperature, especially its increment, to induce the maturation

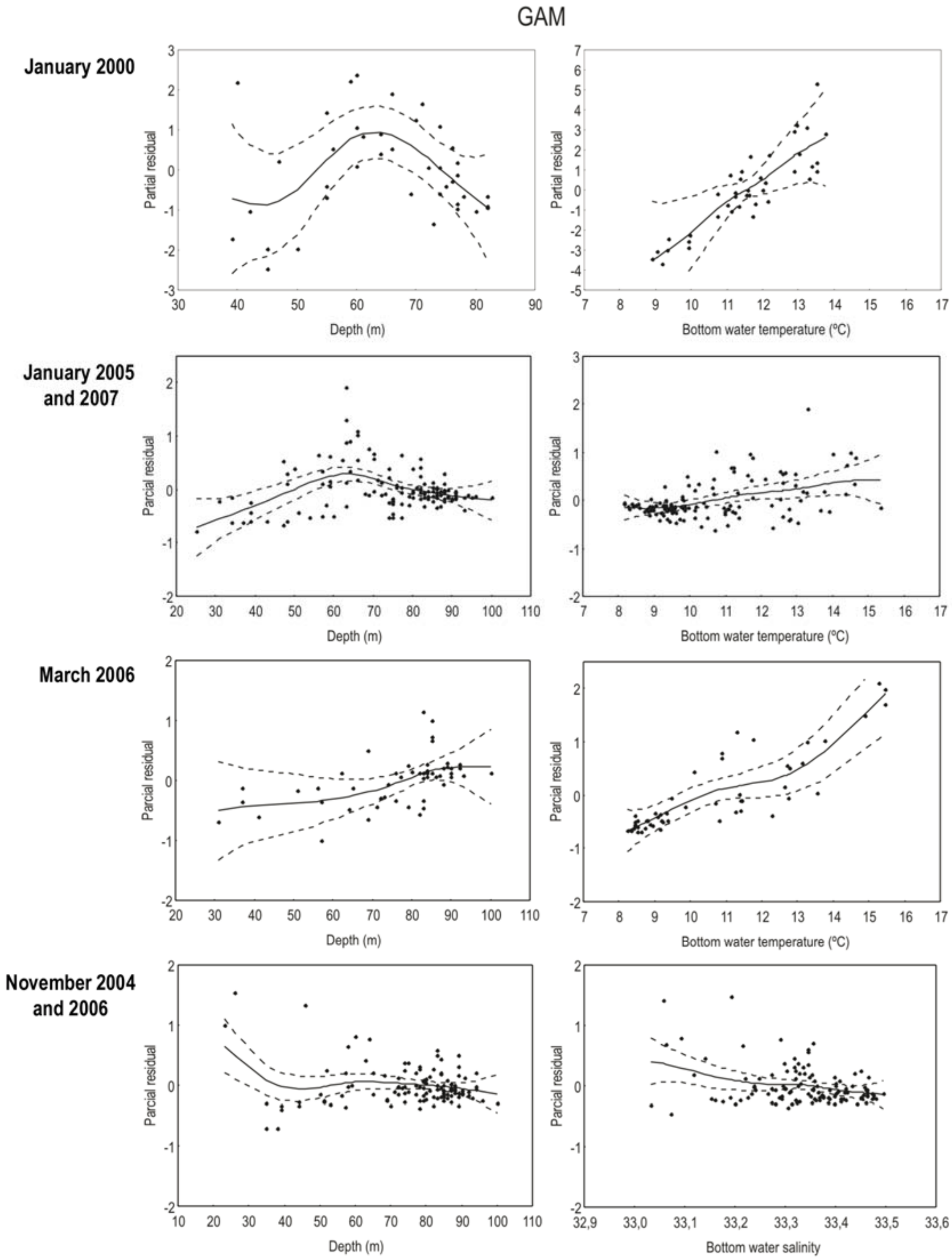

Figure 3. Mature females. Relationship among the partial residual and the considered environmental variables (dots) with the smother line (full line) obtained from the cubics splines. 95% confidence interval (cut line).

Figura 3. Hembras maduras. Relación entre el residuo parcial y la variable ambiental considerada (puntos), con la curva de suavización (línea llena) obtenida a partir de splines cúbicos. Intervalo de confianza al 95% (líneas cortadas).

process and spawning in captivity conditions has been widely studied, being considered tropical waters penaeid prawns of commercial importance (Provenzano, 1985) such as *Penaeus stylirostris* of Baja California, México (Robertson *et al*., 1991), *Penaeus duorarum* of the Mexican east coast (Cripe, 1994) and *Penaeus merguiensis* of the Australian north coast (Hoang *et al*., 2002, 2003).

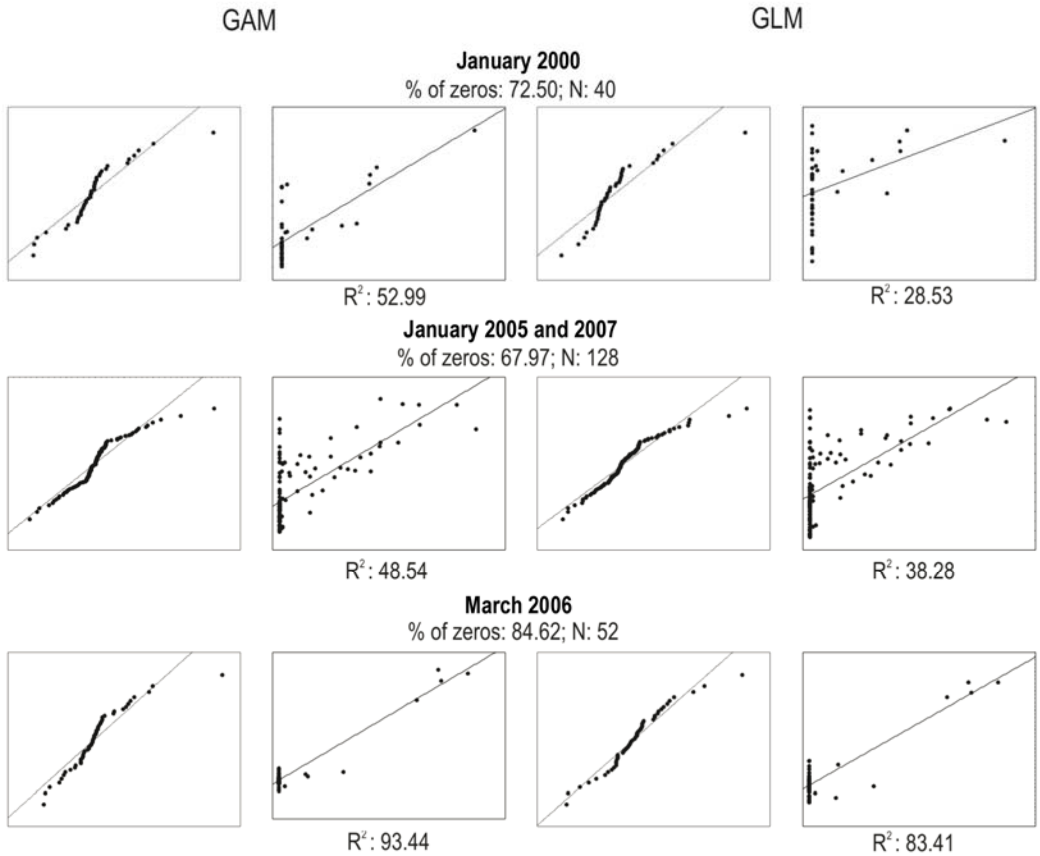

Figure 4. Impregnated females. Residual normal probability plot, relationship among predictive and observed values in each period. Explained variance percentage by the model R^2 and null data percentages in each period.

Figura 4. Hembras impregnadas. Diagramas de normalidad de los residuos y relación entre los valores predictivos y observados, para cada período. Porcentaje de varianza explicada por el modelo R^2 y porcentaje de datos nulos en cada período.

Alpuche *et al.* (2005) who made a bibliographic compilation of the biochemical answers to environmental variations in penaeid indicated that the most influential parameter in prawn and shrimp reproduction is temperature oscillation that may cause retrocession in ovarian development and loss of spermatic quality.

Castilho *et al.* (2008a) in their study about reproduction and recruitment of the South American red shrimp, *Pleoticus muelleri* from the southeastern coast of Brazil indicated a continuous reproductive pattern for *P. muelleri* with the temperature as the environmental stimulus for the ovary development cycle. The phytoplankton production, during spring and summer also seem to adjust the reproductive behaviour.

The fact that the largest concentrations of mature and of impregnated females are found at certain depth range may be related to the type of bottom (sediments, benthic communities and a specific trophic richness) and the presence of frontal systems favourable for larvae and juveniles development.

Aragon-Noriega *et al.* (1999) in their study performed about the spatial distribution and relative abundance of *Litopenaeus stylirostris* and *Farfantepenaeus californiensis* spawning population of the northen California Gulf indicated that the largest abundances locate between 9 and 38 m depth. According to the authors, shrimp is concentrate in coastal zones seeking for the most suitable bottom for larvae arrival and nursery ground. A similar distribution was observed for rock shrimp *Sicyonia penicillata* in Kino Bay, México. Spawners are distributed in coastal areas of the bay, where warm and shallow waters prevail. In the study, those places are considered as breeding and recruitment areas of juveniles to the fishery (López-Martínez *et al.*, 1999). Roux *et al*. (1995) and Roux & Fernández (1997) in studies about the spatial distribution and relative abundance of the benthic communities in the San

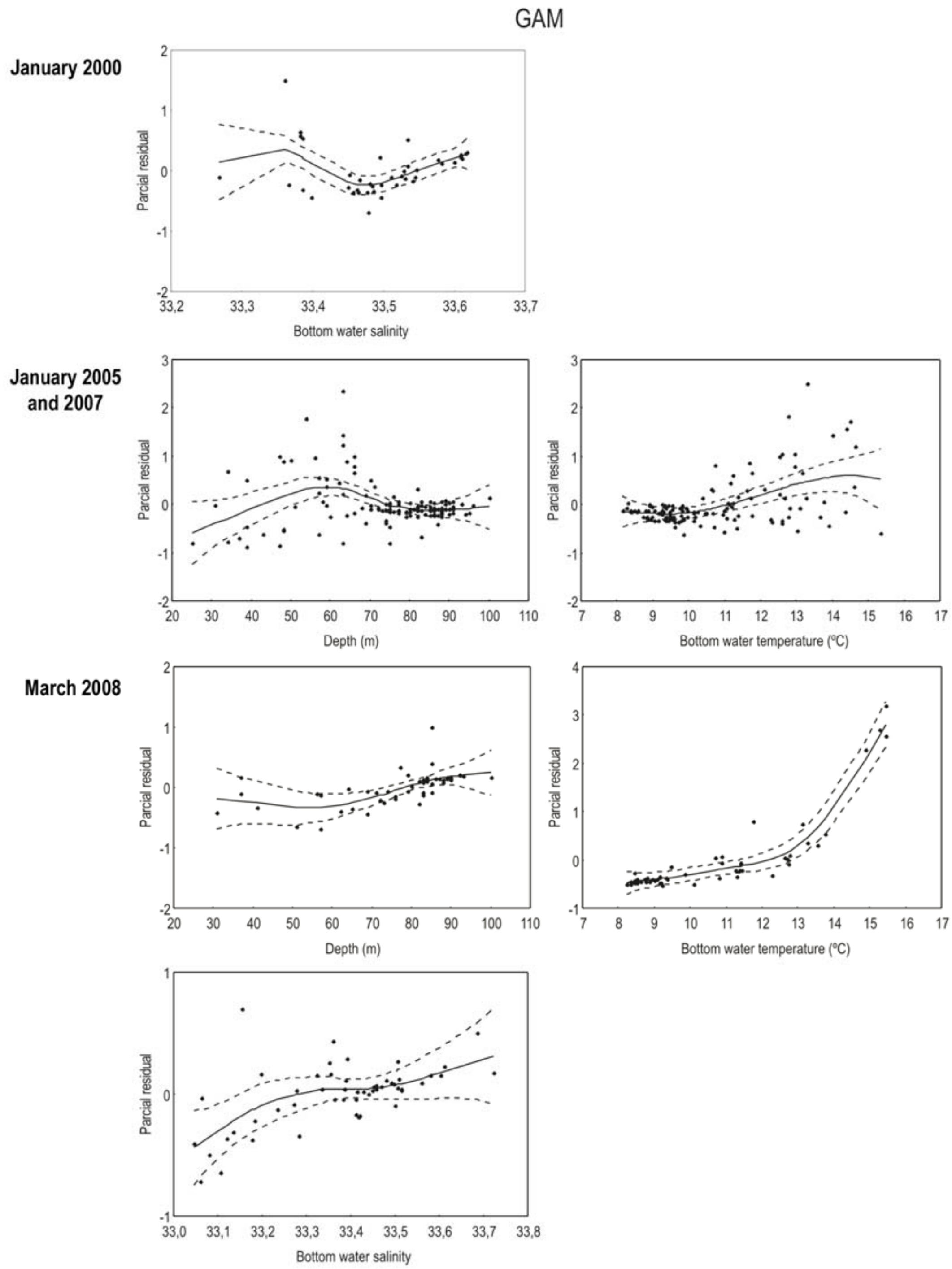

Figure 5. Impregnated females. Relationship among the partial residual and the considered environmental variables (drops) with the smother line (full line) obtained from the cubic spline. 95% confidence interval (cut line).

Figura 5. Hembras impregnadas. Relación entre el residuo parcial y la variable ambiental considerada (puntos), con la curva de suavización (línea llena) obtenida a partir de splines cúbicos. Intervalo de confianza al 95% (líneas cortadas*).*

Jorge Gulf, indicated between the 50-70 m depth - where the largest concentrations of mature and of impregnated shrimp females are located - the presence of bottoms and benthic communities structures advantageous for the refuge and development of juveniles.

The frontal systems, of coastal development, are characterized for their high primary and secondary

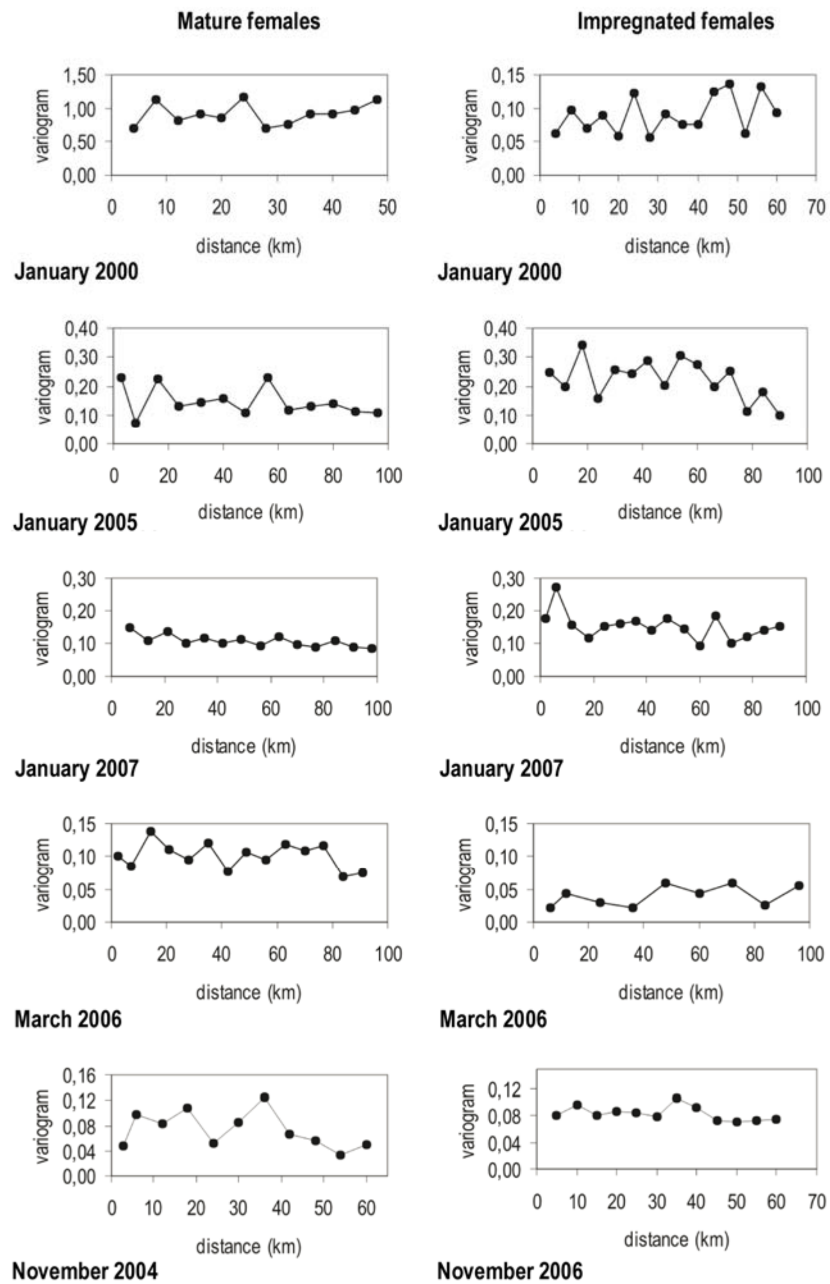

Figure 6. Mature and impregnated females. Experimental semi-variograms corresponding to GAM residuals for each analyzed period.

Figura 6. Hembras maduras y hembras impregnadas. Semi-variogramas experimentales correspondientes a los residuales de los GAM, para cada período analizado.

productivity. The presence of mature females in those areas would secure larval survival (Fernández *et al.*, 2009). In the extremes of San Jorge Gulf, of lesser depth, the vertical mix induced by winds and tides generates fronts of tides of seasonal development and permanence during spring and end of fall. Besides, the coastal waters that enter the gulf from the Magallanes Strait generate, in the southern area, an intense thermohaline front of seasonal permanence and variable position that develops in winter, spring and summer to displace to the north in fall (Guerrero & Piola, 1997; Cucchi-Colleoni & Carreto, 2003). It was also discussed by Castilho *et al.* (2008a).These authors mentioned that the food availability for larval protozoea may be an important selective factor shaping the seasonal breeding pattern in this species. Boschi (1989) also suggested the same relationship.

During the studied period the location of the largest concentrations of mature and of impregnated females during March 2006 in zones deeper than the ones registered in January 2000, 2005 and 2007 could be related to the frontal system displacement (Akselman, 1996; Guerrero & Piola, 1997).

As regards the relation among mature and impregnated females and bottom water salinity, different studies refer to the importance that this factor has in prawns and shrimps life cycle. However, during the last years the majority of researchers have considered the influence of salinity in prawn survival as a secondary factor. Macias-Ortiz (1968), when analyzing tolerance of prawn to temperature and salinity, observed that these penaeids are resistant to a large variation of salinity and that growth continues under any condition. The author concludes that growth, development and survival are more closely related to other factors than to salinity.

Most studies on importance of salinity in prawns and shrimps life cycle were in larvae and juveniles captive conditions. About this topic may be mentioned the works of Rothlisberg (1998) and Zacharia & Kakati (2004).

Rothlisberg (1998) studied the effect of salinity and temperature on growth and survival of postlarvae and juveniles of several species of *Peneaus* and indicated that production (increase in biomass) of *Peneaus marguiensis* is more sensitive to temperature than to salinity.

Zacharia & Kakati (2004) in the research on optimal salinity and temperature for *Penaeus merguiensis* larval development observed that salinity had a larger influence than temperature in survival and development of larvae. The ideal values for larval development was 30-35 psu.

According to Sastry (1983), the influence of salinity on the reproductive cycle of crustaceans has been less studied than the effects of temperature. The author states that this is a parameter important for those species that spend their life cycle between oceanic (adults) and estuarine waters (juveniles) and that the effects produced are less evident than those of the temperature. Sastry (1983) indicated that, with the exception of *Metapenaeus bennettae*, the majority of the panaeids that in the adults phase can not migrate towards waters of a certain salinity level do not mature.

According to all of the above discussed and with the given results in this study where relationship with the salinity decreases for mature females and increases for impregnated females, would be necessary to develop deeper studies, in experimental condition, about the importance of this parameter as another important influential variable in ovarian development.

REFERENCES

Akselman, R. 1996. Estudios ecológicos en el Golfo San Jorge y adyacencias (Atlántico sudoccidental). Distribución, abundancia y variación estacional del fitoplancton en relación a factores físico-químicos y a la dinámica hidrográfica. PhD Thesis, Universidad de Buenos Aires, Buenos Aires, 234 pp.

Alpuche, J., A. Pereyra & C. Agundis. 2005. Respuestas bioquímicas de camarones marinos a factores ambientales. Redvet, 6(5): 10 pp.

Aragón-Noriega, E., C. Cervantes-Valle, A. García-Juárez & L. Calderón-Aguilera. 1999. Abundance relative and spatial distribution of the shrimps spawning population of the northern from California Gulf Turing the summer 1996. Cien. Mar., 3(9): 37-41.

Boschi, E.E. 1989. Biología pesquera del langostino del litoral patagónico de Argentina (*Pleoticus muelleri*). Ser. Contrib. INIDEP, Mar del Plata, 646: 1-71.

Boschi, E.E. 1997. Las pesquerías de crustáceos decápodos en el litoral de la República Argentina. Invest. Mar., Valparaíso, 25: 19-40.

Bertuche, D., C. Fischbach & J. De la Garza. 2000b. La fluctuación de la abundancia de langostino en el Golfo San Jorge. Un análisis premilitar de su relación con el manejo pesquero y los cambios del contexto climático global. INIDEP Inf. Téc. Int., 45: 14 pp.

Bertuche, D., C. Fischbach, A. Roux, M. Fernández & R. Piñero. 2000a. Langostino (*Pleoticus muelleri*). In: S. Bezzi, R. Akselman & E. Boschi (eds.). Síntesis del estado de las pesquerías marítimas argentinas y de la cuenca del Plata. Años 1997-1998, con la actualización de 1999. INIDEP, Mar del Plata, pp. 179-190.

Bertuche, D., J. De La Garza, M. Fernández, P. Moriondo, R. Piñero & A. Roux. 2005. Estudio de las potenciales afectaciones de las distintas actividades económico-productivas realizadas en la zona costera patagónica, en especial en el Golfo San Jorge, sobre las especies bentónicas, en relación a la evolución de aquellas definidas como indicadoras. Consultora Serman & Asociados S.A., Informe Proyecto Langostino, INIDEP, 162 pp.

Castilho, A.L., R. Da Costa, A. Fransozo & M.L. Negreiros-Fransozo. 2008a. Reproduction and recruitment of the South American red shrimp, *Pleoticus muelleri* (Crustacea: Solenoceridae), from the southeastern coast of Brazil. Mar. Biol. Res., 4: 361-368.

Castilho, A.L., M. Pie, A. Fransozo, A. Pinheiro & R. Costa. 2008b. The relationship between environmental variation and species abundance of shrimp community (Crustacea: Decapoda, Penaeoidea) in south-eastern Brazil. J. Mar. Biol. Ass. U.K., 88(1): 119-123.

Costa, R.C., A. Fransozo & A. Pinheiro. 2004. Ecological distribution of the shrimp *Pleoticus muelleri* (Bate, 1888) (Decapoda: Penaeoidea) in southeastern, Brazil. Hydrobiologia, 529(1): 197-205.

Cripe, G. 1994. Induction of maturation and spawning of pink shrimp *Penaeus duorarum* by changing water temperature, and survival and growth of young. Aquaculture, 128(314): 255-260.

Cucchi-Colleoni, D. & J. Carreto. 2003. Variabilidad espacio temporal de la biomasa fitoplanctónica en el Golfo San Jorge. Resúmenes de la V Jornadas Nacionales de Ciencias del Mar, Mar del Plata, 94 pp.

Fernández, M., D. Hernández & A. Roux. 2007. Distribución espacial del langostino patagónico *(Pleoticus muelleri*, (Bate, 1888)) y su relación con las variables físico-químicas del contexto ambiental. Rev. Biol. Mar. Oceanogr., 42(3): 335-344.

Fernández, M., D. Hernández & A. Roux. 2009. Análisis de la relación entre la abundancia relativa de las hembras maduras e impregnadas de langostino patagónico *Pleoticus muelleri* (Bate, 1888) y las variables ambientales aplicando modelos aditivos generalizados y modelos lineales generales. Resúmenes del I Simposio Iberoamericano de Ecología Reproductiva, Reclutamiento y Pesquerías. Vigo, pp. 46.

Guerrero, R. & A. Piola. 1997. Masas de agua en la plataforma continental. In: E. Boschi (ed.). El Mar Argentino y sus recursos pesqueros. INIDEP, Mar del Plata, pp. 107-118.

Garibaldi, L. & S. Busilacchi. 2002. Lista ASFIS de especies para los fines de estadística pesquera. Serie de Referencias ASFIS, 15: 248 pp.

Hass, H., E. Lamon, K. Rose & R. Shaw. 2001. Environmental and biological factors associated with the stage-specific abundance of brown shrimp (*Penaeus aztecus*) in Louisiana, applying a new combination of statistical techniques to long term monitoring date. Can. J. Fish. Aquat. Sci., 58: 2258-2270.

Hastie, T. & R. Tibshirani. 1990. Generalized additive models. Chapman & Hall, London, 335 pp.

Hoang, T., S. Lee, C. Keenan & G. Marsden. 2002. Maturation and spawning performance of pond-reared *Penaeus merguiensis* in different combinations of temperature, light intensity and photoperiod. Aquacult. Res., 33(15): 1243-1252.

Hoang, T., S. Lee, C. Keenan & G. Marsden. 2003. Improved reproductive readiness of pond-reared broodstock *Penaeus merguiensis* by environmentakl manipulation. Aquaculture, 221(1-4): 523-534.

Journel, A.G. & Ch.J. Huijbregts. 1978. Mining geostatistics. Academic Press, London, 600 pp.

López-Martínez, J., F. García Domínguez, E. Alcántara-Razo & E. Chávez. 1999. Período reproductivo y talla de madurez masiva del camarón de la roca *Sicyonia penicillata* (Decapoda: Sicyoniidae) en Bahía Kino, Sonora, México. Rev. Biol. Trop., 47(1-2): 109-117.

Macchi, G., M. Iorio & A. Aubone. 1998. Estimación de la fecundidad del langostino argentino *Pleoticus muelleri* (Bate, 1888) de patagonia (sur de Argentina). Bol. Inst. Esp. Oceanogr., 14(1-2): 19-29.

Macias-Ortiz, J. 1968. Frecuencia de camarón postlarval (*Penaeus fabricius*, 1798) relacionada con la temperatura y salinidad en la costa de Ciudad Madero, Tamaulipas, México. FAO Fish. Rep., 57(2): 321-329.

McCullagh, P. & J. Nelder. 1989. Generalized linear models. Chapman & Hall, London, 511 pp.

O'Brien, L. & P. Rago. 1996. An application of the generalized additive model to groundfish Survey Data with Atlantic cod off the northeast coast of the United States as an example. NAFO Sci. Coun. Studies, 28: 79-95.

Powers, L. & D. Bliss. 1983. Terrestrial adaptations. In: F.J. Vernberg & W.B. Vernberg (eds.). The biology of crustacea. Academic Press, New York, pp. 335-359.

Provenzano, J. 1985. Comercial culture of decapod crustaceans. In: A. Provenzano Jr. (ed.). The biology of crustacea, Academic Press, New York, pp. 269-303.

Robertson, L., W. Bray & A. Lawrence. 1991. Reproductive response of *Penaeus stylirostris* to temperature manipulation. J. World Aquacult. Soc., 22(2): 109-117.

Roux, A. & M. Fernández. 1997. Caracterización de los fondos de pesca del langostino *Pleoticus muelleri* en el Golfo San Jorge y litoral de la provincia de Chubut, Argentina. INIDEP, Inf. Téc., 13: 1- 28.

Roux, A, M. Fernández & C. Bremec. 1995. Preliminary survey of the benthic communities of patagonian shrimp fishing grounds in San Jorge Gulf (Argentina). Cien. Mar., 21(3): 295-310.

Rothlisberg, P. 1998. Aspects of penaeid biology and ecology of relevance to aquaculture: a review. Aquaculture, 164(1-4): 49-65.

Ruiz, A. & L. Mendia. 2008. Observaciones morfométricas y reproductivas en el langostino *Pleoticus muelleri* Bate, 1888 procedente de embarcaciones comerciales del Puerto Rawson, Argentina. Rev. Biol. Mar. Oceanogr., 43(3): 675-680.

Sastry, A.N. 1983. Ecological aspects of reproduction. In: F.J. Vernberg & W.B. Vernberg (eds.). The biology of crustacea: Vol. 8. Environmental adaptations, Academic Press, New York, pp. 179-270.

Secretaría de Agricultura, Ganadería, Pesca y Alimentación (SAGPyA). 2001. Capturas marítimas totales 2001. Argentina, 8 pp.

Segura, A.M., E. Delgado & A. Carranza. 2008. La pesquería de langostino en Punta del Diablo (Uruguay): un primer acercamiento. Pan. Am. J. Aquat. Sci., 3(3): 232-236.

Received: 5 April 2010; Accepted: 9 November 2010

Venables, W.N. & C.M. Dichmont. 2004. GL Ms, GAMs and GLMMs: an overview of theory for applications in fisheries research. Fish. Res., 70: 319-337.

Xiang, D. 2001. Fitting generalized additive models with the GAM procedure. SAS Institute, Paper P256-26: 8 pp.

Ye, Y., H. Mohammed & J. Bishop. 1999. Depth, temperature and salinity preferences of newly recruit penaeid shrimps in Kuwait waters. Fish. Oceanogr., 8(2): 128-138.

Yee, Th.W. & N.D. Mitchell. 1991. Generalized additive models in plant ecology. J. Veg. Sci., 2: 587-602.

Zacharia, S. & V. Kakati. 2004. Optimal salinity and temperature for early developmental stages of *Penaeus merguiensis*. Aquaculture, 232(1-4): 373-382.

Zar, J. 1996. Biostatistical analysis. Prentice Hall, New Jersey, 662 pp.