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Temporal variability of the bivalve *Erodona mactroides* BOSC, 1802 during and after the *El Niño* phenomenon (2002/2003) in a subtropical lagoon, southern Brazil

Variabilidade temporal do bivalve *Erodona mactroides* BOSC, 1802 durante e após o fenômeno *El Niño* (2002/2003) em uma laguna subtropical, sul do Brasil

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Abstract: Aim: The aim of this work was to study the relationships between temporal variability of *Erodona mactroides* and abiotic parameters of the water column and the substrate in a shallow embayment of the Patos Lagoon estuarine region in southern Brazil; **Methods:** Samples were taken with a PVC corer (10 cm diameter) buried 10 cm into the sediment between October 2002 and December 2004. Each month 18 biologic samples were taken, six substrate samples were analyzed for sediment grain size and organic matter content and sediment deposition rates were determined by 12 sediment traps every two weeks. Salinity, water temperature, water level and estuarine freshwater discharge were measured daily. Abiotic parameters and bivalve densities were tested among months with registered mortality events by ANOVA (One-way, p = 0.05), being the *E. mactroides* seasonal variability tested by Kruskal-Wallis (p = 0.05). Regression analyses among abiotic parameters and Spearman's "R" correlation analyses between biological and environmental data were both performed; **Results:** Two periods were identified with distinct features: one at the beginning of the study when observed limnetic conditions in the estuarine region were caused by the ENSO - *El Niño* 2002/2003 phenomenon when an absence of *E. mactroides* was registered as well as a higher percentages of fine sediments and lower percentages of organic matter. The second period was characterized by a decreasing influence of the *El Niño* and predominance of mixohaline conditions, recruitments and increasing densities of *E. mactroides* with a successive decrease of mean densities due to three mortality events, lower percentages of fine sediments and higher percentages of organic matter; **Conclusions:** The present study provides evidences that the occurrence of *E. mactroides* in the southern estuarine region depends on the water flow regime from the drainage basin, which characterizes species recruitment as temporally unpredictable and affects its persistence through time due to adverse conditions that influence species development like events of fine sediment deposition.

Keywords: *Erodona mactroides*, recruitment, *El Niño*, estuary, Patos Lagoon.

Resumo: Objetivo: O objetivo do presente trabalho foi avaliar as relações entre a variabilidade temporal de *Erodona mactroides* e os parâmetros abióticos da coluna d'água e do substrato em uma enseada rasa da região estuarina da Lagoa dos Patos, sul do Brasil; **Métodos:** As amostras foram coletadas com um extrator de PVC (10 cm de diâmetro), enterrado a 10 cm no interior do sedimento, entre Outubro/02 e Dezembro/04. Em cada mês foram coletadas 18 amostras biológicas, seis réplicas de sedimento para análises granulométricas e teor de matéria orgânica, além de 12 réplicas quinzenais de experimentos de deposição de sedimentos. A salinidade, temperatura da coluna d'água, profundidade e vazão do estuário foram medidas diariamente. Os parâmetros abióticos e densidades do bivalve entre os meses em que foram observados eventos de mortalidade foram testados através de ANOVA (Uma via, p = 0,05), e a variabilidade sazonal de *E. mactroides* foi testada através da análise de Kruskal-Wallis (p = 0,05). Foi aplicada análise de Regressão entre os dados abióticos e Correlação de Spearman "R" entre os dados biológicos de densidade e parâmetros ambientais; **Resultados:** Foram identificados dois períodos com características distintas: no início do estudo foram registradas condições limnéticas na região estuarina devido ao fenômeno ENSO – *El Niño* 2002/2003, quando foi registrada a ausência de *E. mactroides*, maiores percentuais de sedimento finos e menores percentuais de matéria orgânica. O segundo período foi caracterizado pela diminuição da influência do *El Niño* e predominância de condições mixohalinas, recrutamentos e pelo aumento das densidades médias de *E. mactroides* com sucessivos decréscimos no número de organismos devido a três eventos de mortalidade, menores percentuais de sedimentos finos e maiores percentuais de matéria orgânica; **Conclusões:** O presente estudo evidencia que a ocorrência de *E. mactroides* na porção sul da região estuarina, que depende do regime de vazão da laguna, caracteriza os recrutamentos como temporalmente imprevisíveis, e sua persistência é afetada por condições desfavoráveis a seu desenvolvimento como eventos de deposição de sedimentos finos.

Palavras-chave: *Erodona mactroides*, recrutamento, *El Niño,* estuário, Lagoa dos Patos.

1. Introduction

The mollusc *Erodona mactroides* Bosc, 1802 is one of the most abundant bivalves found at the mixohaline regions of rivers, lagoons and estuaries in southern Brazil, Uruguay and Argentina (Costa, 1971; Jorcin, 1996), occurring at Rio de la Plata affluent rivers near Buenos Aires (Carcelles, 1941) and also at Laguna Rocha, as well as streams and rivers along the Uruguayan coast (Jorcin, 1996; Muniz and Venturini, 2001). Along the coast of the State of Rio Grande do Sul in southern Brazil, the species is found at high densities in the Patos Lagoon estuary (Rosa-Filho and Bemvenuti, 1998; Bemvenuti and Netto, 1998), where is a common macrobenthic species (Rosa and Bemvenuti, 2007; Colling et al., 2007).

This Erodonidae species is inequivalve with the right valve large and convex, displaying subtrigonal shells with anterior side rounded and posterior rostrate (Rios, 2009). As a subsurface inhabitant and suspension feeder, this species plays an important ecological role in the Patos Lagoon due to the exposure of its shell in the bottom surface, which can be considered the unique biological hard substrate for macrobenthic communities on soft bottoms, allowing the attachment of epibionthic organisms (Bemvenuti et al., 1978). As a consequence of its high abundance and wide distribution in the Patos Lagoon, *E. mactroides* is considered the main phytoplankton consumer among macrobenthic invertebrates (Bemvenuti and Netto, 1998), being responsible for an important energy flux from the water column to the benthic environment, in which the species is reported as an important food item for major decapod and fish species (Araújo, 1984; Bemvenuti, 1997a).

The first records of *E. mactroides* in the Patos Lagoon were reported by von Ihering (1885), while another study, concerning the distribution of Thecamoeba and Foraminifera species, mentions the presence of this species in the southern portion of the lagoon (Closs, 1962). The spatial distribution of the macrobenthic fauna in the Patos Lagoon was previously analyzed by Bemvenuti and Netto (1998), observing the wide distribution of *E. mactroides* along the entire lagoon and the estuarine region. This bivalve inhabits large areas at the Patos Lagoon upper portion, where all size classes are found and high densities of adults occur, while southwards in the estuarine region only juveniles were observed (Bemvenuti et al., 1978; Capítoli et al., 1978). Recently, temporal variability analysis of macrozoobenthos in Patos Lagoon estuary showed that high densities of the bivalve occur associated with limnetic conditions (Colling et al., 2007).

The larvae of *E. mactroides* of the adult reproductive stock in the upper estuary which are carried by ebb tides to the south during spring and summer, give origin the observed recruitments in sheltered embayments in southern estuarine regions. At these sites, juvenile massive mortalities were observed on later autumn, suggesting that the obstruction of their filtration system apparatus may be the cause of death due to deposition of suspended matter (Bemvenuti, 1997b).

Concerning the general size, the bivalve lengths range between 0.42-43.22 mm in Laguna Rocha - Uruguay (Jorcin, 1996) and between 1.00-35.00 mm in the Patos Lagoon, where individuals smaller than 20 mm were considered juveniles (Geraldi, 2002). Inside the Pando Stream, Uruguay, Passadore et al. (2007) reported organisms smaller than 14 mm as recruits.

Considering that larval input from the upper estuary to the southern region depends on the temporal variability of the systems water discharge, the present work aimed to evaluate if recruitment of *E. mactroides* at the lower estuary during spring/summer may be influenced by stochastic events like the *El Niño* phenomena. Besides the water column characterization, recruitment periods and bivalve densities, this work also aimed to investigate the temporal variability of *E. mactroides* densities and evaluate possible mortality events related to substrate dynamics like fine sediment depositions.

2. Material and Methods

Located at the coastal plain of southern Brazil, the Patos Lagoon is classified as the world's largest choked lagoon (Kjerfve, 1986). With a surface area of 10,227 km^2, this coastal lagoon stretches in a NE-SW direction from 30° 30' S to 32° 12' S near the city of Rio Grande. Inside its southern portion an estuarine region of 971 km^2 is found (approximately 10% of the lagoon) which exchanges waters with the Atlantic Ocean through a 20 km long and 0.5-3 km wide inlet. Through tributary rivers and the São Gonçalo channel (Lagoa Mirim watershed), this lagoon receives freshwater from a 201,626 km^2 drainage basin, in which high precipitation and complex patterns of river discharge result in highly dynamic hydrographic processes (Asmus, 1997).

The present study was performed along a 450 m transect of a sheltered shallow plain in the Saco do Arraial embayment (see map in Colling et al., 2007).

Samples were taken monthly from October 2002 to December 2004 in an area with 0.8 m mean depth. At each month, sediment samples ($n = 6$) were taken using a PVC corer (10 cm diameter) buried 10 cm into the bottom to analyse granulometric and organic matter content (OM). Sand, silt and clay proportions were determined according to Suguio (1973) through sieving (particles > 0.062 mm) and pipette analyses (particles < 0.062 mm) while OM contents were determined through weight loss by combustion according Davies (1974).

Daily water temperature (°C), salinity and water level (cm) were provided by the Brazilian Long-Term Ecological Program databank (PELD – *Programas Ecológicos de Longa Duração – Site 8* – FURG; www.peld.furg.br). Fluvial discharge data from the Patos Lagoon main tributary rivers Jacuí, Taquari and Camaquã (Vaz et al., 2006) were taken daily from the Brazilian Waters Agency (ANA – Agência Nacional de Águas; www.ana.gov.br), being used here to represent the Patos Lagoon drainage basin monthly runoff mean (sum of Jacuí, Taquari and Camaquã river discharges).

Biologic samples were taken monthly ($n = 18$) using the same PVC corer used in the sediment samples, being sieved in the field through a nylon sieve with 0.3 mm mesh size and then fixed in a 4% formaldehyde solution. In the laboratory, *E. mactroides* individuals were sorted from the sediment under stereomicroscope and then preserved in a 70% ethanol solution.

Attaching a milimetric scale (0.5 mm of precision) to Petry plates, measures of the right valve's anteroposterior length were taken from 18,391 individuals in order to evaluate the frequency distribution of *E. mactroides* size classes as well as the species temporal development.

The months used to define the seasons of the present work were as follows: spring (from October to December), summer (January to March), autumn (April to June) and winter (July to September). Salinity, freshwater discharge (m^3/s), water level (cm), silt + clay (%) and OM contents (%) were transformed to *log* (x+1) and tested by ANOVA (One-way; $p = 0.05$) to investigate their temporal differences among seasons. The temporal variability of *E. mactroides* densities was tested by Kruskal-Wallis non-parametric analyses ($p = 0.05$), since normality and homogeneity of these data were not attained, even after several transformations.

Regression analyses were pairwisely executed to the monthly means of silt + clay percentages, OM contents, fluvial discharge, salinity and water level, being used for each pair of data the best R^2 mathematical equation. In order to determine possible significant correlations between biological and environmental data (Zar, 1984) the Spearman's "R" correlation coefficient ($p = 0.05$) were used to compare the monthly means of *E. mactroides* densities to the following standardized abiotic data (Clarke and Warwick, 1994): silt + clay percentages, OM contents, fluvial discharge, salinity and water level.

To evaluate the significance of declining in the *E. mactroides* densities there were performed ANOVA tests (One-way; $p = 0.05$) on each pair of the following months: August-September 2003, April-May 2004 and October-November 2004, all considered here as mortality events due to expressive reductions in the bivalve densities.

To quantify the depositional processes that are able to interfere in the survival and persistence of *E. mactroides* through time, experiments on sediment deposition were fortnightly executed utilizing 12 particle interceptor traps. These sediment traps were built using an external PVC pipe (7.5 cm diameter × 15 cm high) with 10 PVC tubes inside of it (1 cm diameter × 10 cm high) fixed on a solid base buried into the substrate. These traps were placed on the sampling site 15 days before the biological sampling and then removed to the laboratory, where the caught sediments were weighted (total weigh expressed in g) and their granulometric fractions were determined. These experiments were executed between December 2002 and August 2004, except for January, March, June and October 2003 and July 2004.

3. Results

Higher water temperatures were registered during summer/03 (25.8 °C) and summer/04 (24.8 °C) while lower ones were observed during winter/03 (13.6 °C) and winter/04 (13.1 °C). The water temperature along spring seasons were always warmer than those registered in autumn seasons.

Significant differences in the mean freshwater discharge were found among the evaluated periods (Table 1; Figure 1a). From spring/02 to summer/03 there were registered the highest values of discharge, as observed on October 2002 (5,982 m^3/s). After these elevated runoff rates in the begging of the study, it was observed significant decreasing discharges with the lowest rates being registered from summer/04 to autumn/04, like those on March 2004 (about 307 m^3/s).

Salinity data showed significant differences among seasons (Table 1) and great temporal variability (Figure 1b), ranging from zero (spring/02 and summer/03) to 35 (autumn/04). Lower values were registered during the winter/02 (previously to the sampling period), along spring/02 and on early summer/03, with fortnightly means not higher than five, except on September 2002. Increasing salinities were observed from later summer/03 (fortnightly means between 5 and 15) to early summer/04, when low salinity values were registered, followed again by an increase in salinity from summer/04 to winter/04, period when were registered fortnightly means often higher than 15.

It was calculated for the Patos Lagoon estuarine region a decadal mean of water level (MWL) comprising the daily values registered in the PELD databank between January 1994 and December 2004, from which it was calculated a MWL equal to 48.7 cm. For the spring/02 and summer/03, the mean water level registered were 70.0 cm, a value higher than that decadal mean due to the great freshwater discharge (Figure 1c). On the other hand, from the spring/03 to spring/04 there were registered water levels between 30 and 50 cm, values significant lower than those observed in the early sampling period (Table 1).

Percentages of fine sediments (silt + clay) as well as the percentages of organic matter in the sediment varied significantly among the analyzed periods (Table 1). Higher percentages of silt and clay

Table 1. Results of temporal analyses on the environmental data and *Erodona mactroides* mortality events (One-way ANOVA; p = 0.05) and on the *E. mactroides* mean densities (Kruskal-Wallis non-parametric analysis; p = 0.05).

Parameter		DF	SS	F	p
Discharge					
	Periods	8	3472	6.68	0.000
	Residual	18	1169	-	-
Salinity					
	Periods	8	547	4.19	0.005
	Residual	18	249	-	-
Water level					
	Periods	6	4559	14.36	0.000
	Residual	14	741	-	-
Fine sediments					
	Periods	8	5	21.22	0.000
	Residual	153	5	-	-
Organic matter					
	Periods	8	1	11.92	0.000
	Residual	153	2	-	-
E. mactroides density					
	Periods	7	-	-	0.000
E. mactroides mortality					
	Aug-Sep/03	1	2870	6.57	0.014
	Apr-May/04	1	16883	12.41	0.001
	Oct-Nov/04	1	30942	6.39	0.016

DF: degrees of freedom; SS: sum square; F: Fisher's F.

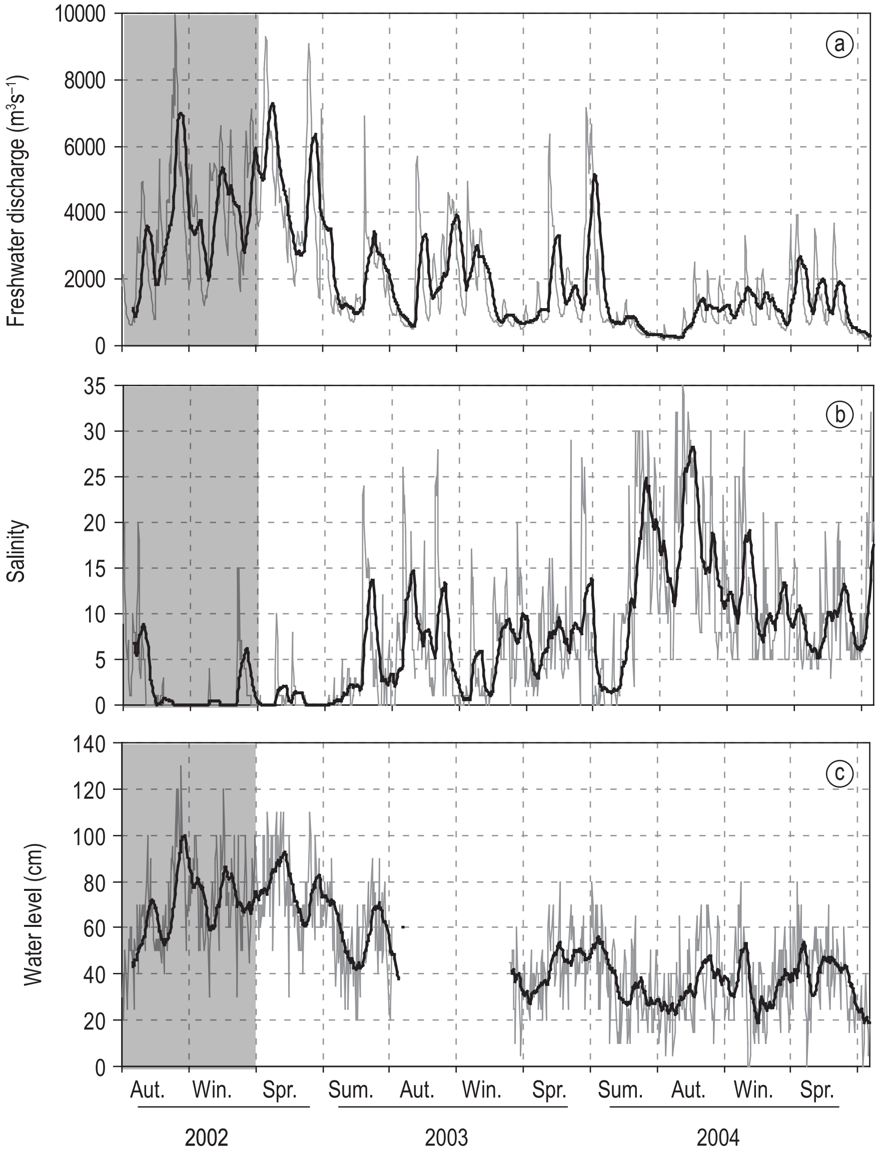

Figure 1. Daily values (grey line) and monthly mean (black line) for the rivers Taquari + Jacuí + Camaquã mean fluvial discharge (a), salinity (b) and water level (c) from April 2002 to December 2004 in the Patos Lagoon. The marked grey area represents the period before sampling.

were registered in spring/02 (21.00% ± 9.90%), summer/03 (9.80% ± 3.63%) and autumn/03 (7.35% ± 5.05%), when a reduction of fine sediments was observed from the winter/03 to autumn/04 (4.26% ± 1.60%; Figure 2). Higher percentages of organic matter (Table 1) were found from autumn/03 (1.15% ± 1.44%) to autumn/04 (1.22% ± 0.27%), while lower values were registered in spring/02 (0.29% ± 0.06%) and summer/03 (0.26% ± 1.12%) - the first two sampling periods - besides the winter/04 (0.74% ± 0.19%).

Pairwised regressions on environmental data (Figure 3) evidenced strong relationships between OM × fine sediments (R^2 = 0.76), salinity × fine sediments (R^2 = 0.59), salinity × water level (R^2 = 0.72) and salinity × discharge (R^2 = 0.50). The abiotic pairwised regression between discharge × water level (R^2 = 0.83) presented the best linear relation throughout the study since periods of elevated runoff are linked to elevations on the water level of the lagoon. These periods of high water level were found to be strongly related to OM contents (R^2 = 0.64), despite the temporal irregularity of this later variable (Figure 2), and also to elevated proportions of fine sediments (R^2 = 0.54). In addition, there were found weak temporal relationships between the following pairwised data: discharge x fine sediments (R^2 = 0.40), salinity × OM (R^2 = 0.36) and discharge × OM (R^2 = 0.30).

The absence of *E. mactroides* in the spring/02 as well as its low densities in summer/03 were responsible to characterize the mean densities of the bivalve along this early periods as significantly lower ($p < 0.05$) than those registered in the subsequent seasons (Table 1). The first occurrence of *E. mactroides* was registered on later summer - autumn/03 (Figure 4), with higher densities occurring along this last season (11,628 ± 6,428 ind.m^{-2}), winter/03 (10,406 ± 6,640 ind.m^{-2}) and spring/03 (8,485 ± 4,280 ind.m^{-2}). Successive density reductions were observed from summer to spring/04 (1,519 ± 1,163 ind.m^{-2}), being these reduced densities significantly lower than those registered for both autumn and winter/03 ($p < 0.05$).

Those bivalves collected in summer/03 and autumn/03 were classified in the size classes between 0.5-3 mm (Figure 5a,b), representing post settled recruits with non calcified shells. Size classes smaller than 1 mm were found until the winter/03, when recruits were not registered anymore. Between winter/03 and spring/03 the occurrence of organisms < 3 mm decreased, period in which individuals of different size classes characterized the development of those recruits (Figure 5c,d). From summer to spring/04 (Figure 5e-h) the modal frequency of lengths were registered between 6 and 9 mm with the biggest individuals reaching 18 mm.

There were found weak temporal relationships between the *E. mactroides* densities and fine sediments ($R^2 = 0.41$), OM contents ($R^2 = 0.25$) and discharge ($R^2 = 0.30$). On the other hand, strong temporal relations were found between *E. mactroides* densities × water level ($R^2 = 0.56$) and *E. mactroides* densities x salinity ($R^2 = 0.70$), mainly due to the absence of the species during the early sampling period associated to high water level and low salinity values, respectively (Figure 6).

The Spearman's correlation coefficients evidenced no significant correlations between the *E. mactroides* densities and all the environmental data except for fine sediments, being found a negative temporal correlation ($p = 0.037$; $R = -0.402$) (Table 2).

The observed reductions in the *E. mactroides* mean densities were found significant for all the following months (Figure 7; Table 1): August-September 2003 (from 13,651 to 8,004 ind.m^{-2}); April-May 2004 (from 6,433 to 2,101 ind.m^{-2}); and October-November 2004 (from 2,852 to 997 ind.m^{-2}).

In the first mortality event (August-September 2003) it was registered an increasing of fine sediments

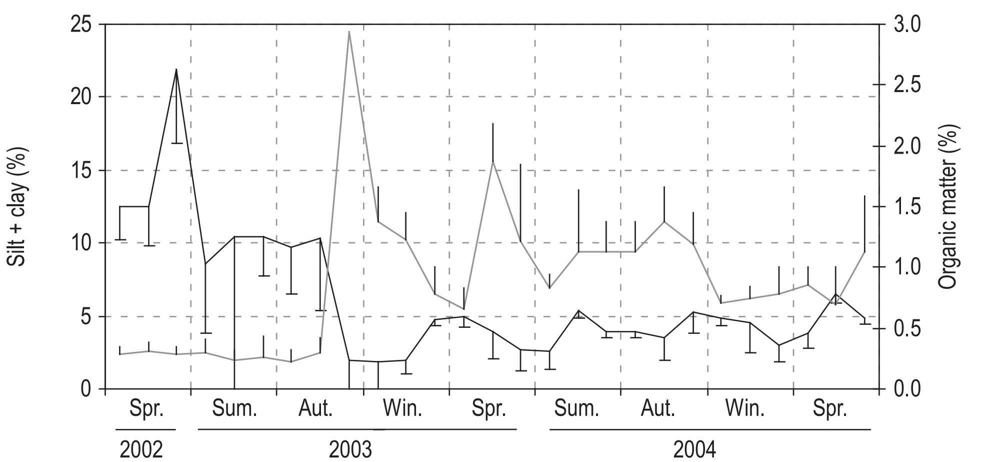

Figure 2. Monthly mean and standard deviation of silt + clay percentages (black line) and organic matter (grey line) registered in the bottom's sediment.

Table 2. Spearman's correlation results between the *Erodona mactroides* mean densities and the environmental data.

	N	R	t (*n*-2)	p
E. mactroides X Fine sediments	27	-0.402	-2.198	0.037
E. mactroides X Organic matter	27	0.251	1.300	0.205
E. mactroides X Water level	22	-0.280	-1.306	0.206
E. mactroides X Salinity	27	0.015	0.076	0.939
E. mactroides X Discharge	27	-0.075	-0.380	0.706

R: Spearman's coefficient.

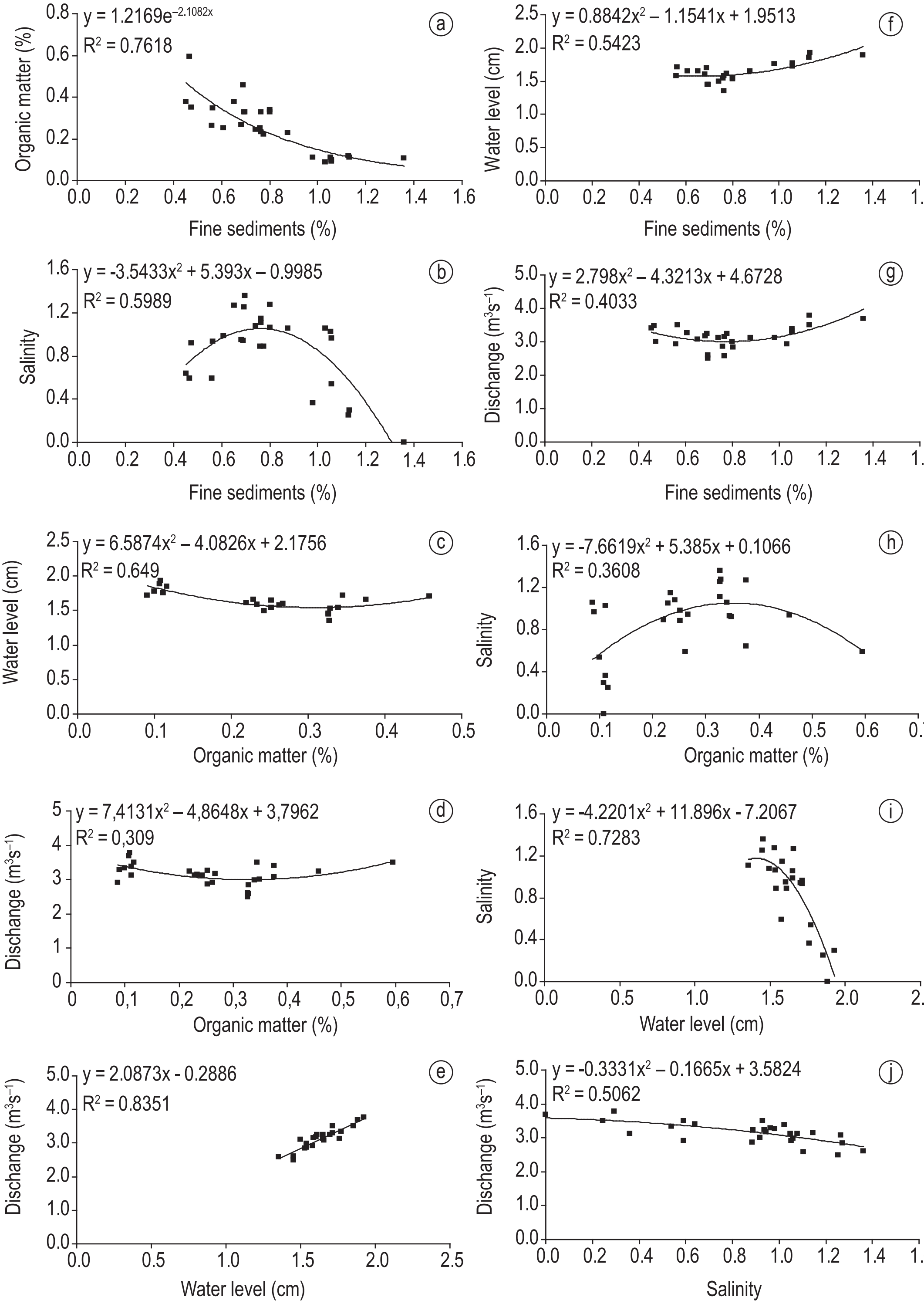

Figure 3. Regression analyses adjusted to *log* (x+1) monthly means of the environmental pairwised data organic matter x fine sediments (a); salinity x fine sediments (b); water level x organic matter (c); discharge x organic matter (d); discharge x water level (e); water level x fine sediments (f); discharge x fine sediments (g); salinity x organic matter (h); salinity x water level (i); and discharge x salinity (j).

in the depositional experiments (Figure 8), in which the weight of fine material raised from 47.63 g on August (88.27% of the total sediment trapped) to 73.44 g on September (89.89%). The sedimentation rates registered for each experiment period were 10,825 g.m^{-2} 15 days^{-1} and 16,690 g.m^{-2} 15 days^{-1} on August and September, respectively (Table 3). As registered on the experiments, it was also observed

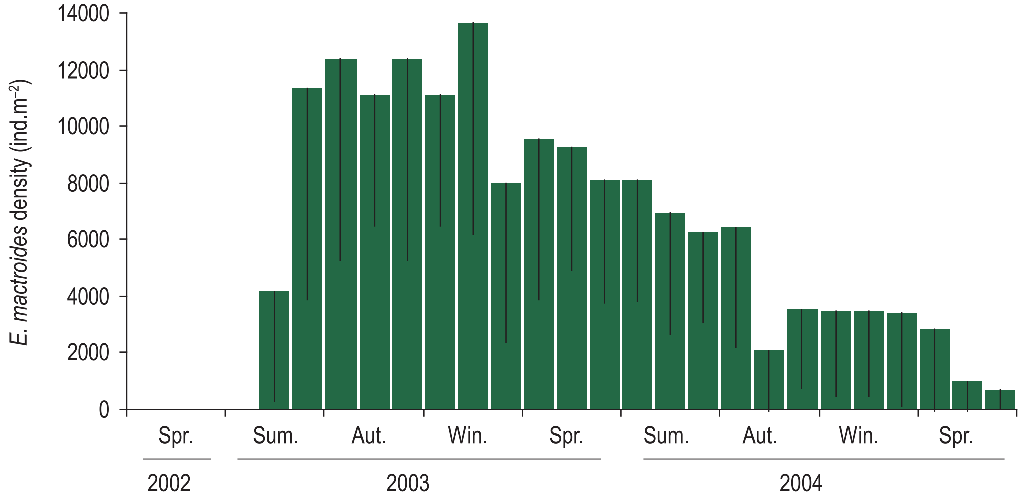

Figure 4. Monthly mean densities (ind.m^{-2}) and standard deviation of *Erodona mactroides* along the study.

Table 3. Results of the total sediment weight (TSW), silt + clay percentages (SCP), registered silt + clay weight (RSCW), calculated silt + clay weight (CSCW), percentage of silt + clay on bottom (SCB) and *Erodona mactroides* densities (*Em*D) registered along the species' mortality events.

	TSW (g)	SCP (%)	RSCW (g)	CSCW (g m^{-2} 15 days^{-1})	SCB (%)	*Em*D (ind.m^{-2})
Aug/03	53.95	0.88	47.63	10,825	0.02	13,651
Sep/03	81.07	0.89	73.44	16,690	0.04	8,004
Apr/04	102.97	0.39	40.54	9,213	0.04	6,433
May/04	87.66	0.67	59.08	13,427	0.03	2,101
Oct/04	-	-	-	-	0.03	2,852
Nov/04	-	-	-	-	0.06	997

for the substrate an increase on its fine sediment rates (Figure 2), ranging from 1.98% on August to 4.75% on September 2003.

In the second mortality event (April-May 2004) the weight of deposited silt + clay fractions raised from 40.54 g on April to 59.08 g on May, with fine sediment percentages increasing from 39.37 to 67.39% (Figure 8). Sedimentation rates in these months also raised from 9,213 g.m^{-2} 15 days^{-1} to 13,427 g.m^{-2} 15 days^{-1} respectively (Table 3), despite the similar values found for the substrate between April (3.97%) and May (3.49%; Figure 2).

During the third mortality event (October-November 2004) the experiments on deposition were not carried out, but the substrate granulometry revealed that the fine sediments percentage increased from October (3.83%) to November (6.53%; Figure 2).

4. Discussion

Our results evidenced that the bivalve *E. mactroides* had a significant temporal variability along the study: its absence in the early sampling period (spring/02); its occurrence in high densities from autumn - winter/03; and its gradual reductions due to three mortality events that lead to its absence in later spring/04.

The environmental variables characterized two periods with distinct features: one in the beginning of the study when there were registered limnetic conditions in the estuarine region caused by the ENSO - *El Niño* 2002/2003 phenomenon, in which there were observed higher percentages of fine sediments and lower percentages of organic matter. The second period was characterized by a decreasing influence of the *El Niño* phenomenon, predominance of mixohaline waters, lower percentages of fine sediments and higher percentages of organic matter.

The Patos Lagoon presents low tidal amplitude and salinity variations strongly influenced by the action of winds (seasonal scale) and hydrological cycles on its drainage basin (interannual scale), in which the predominance of freshwaters inside the estuarine region are associated to NE winds and elevated fluvial discharge; on the other hand, the predominance of marine waters inside the estuary are found to be related to S winds and droughts on

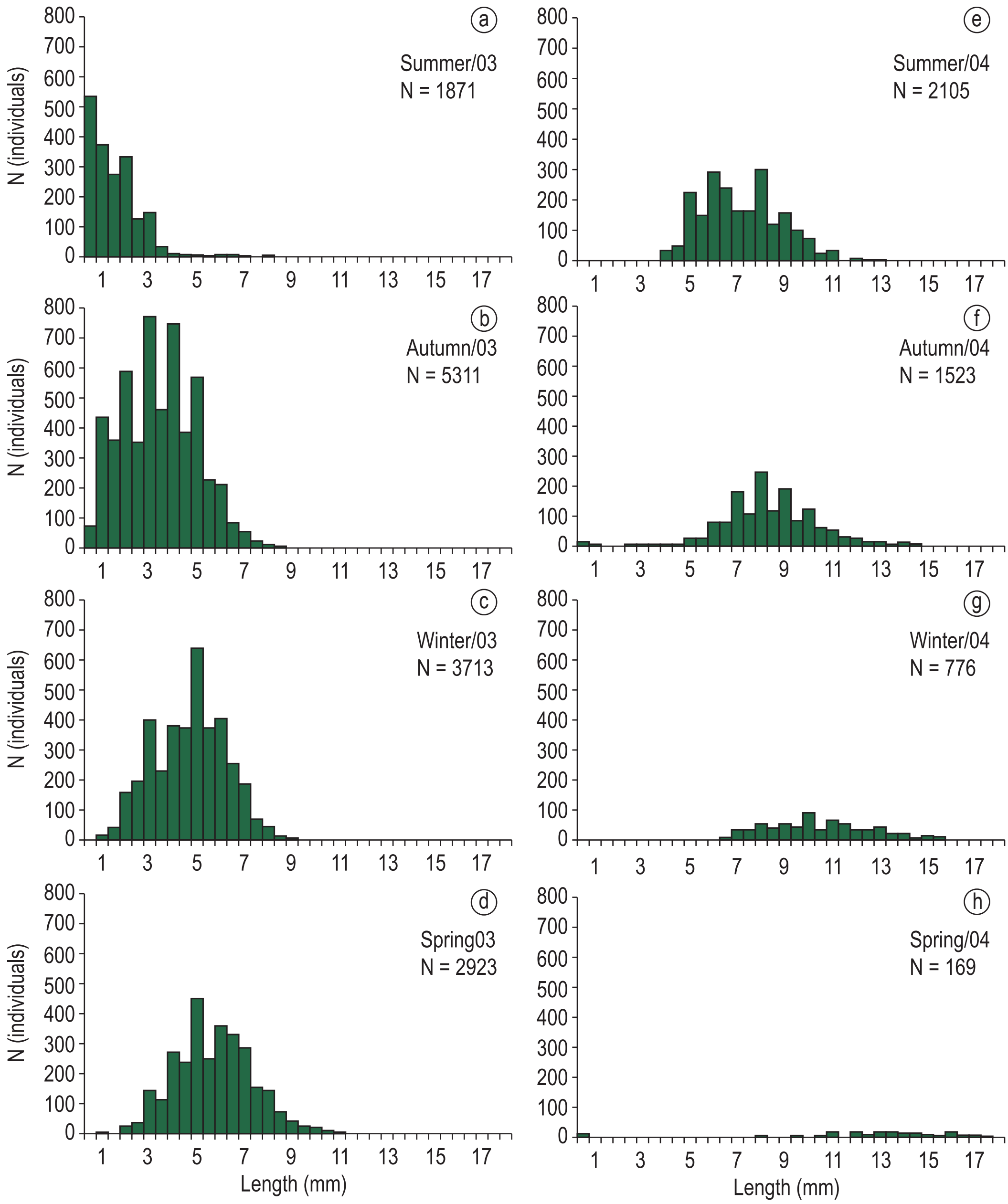

Figure 5. Size frequency distributions (right valve's length, mm) of *Erodona mactroides* along the studied seasons.

the drainage basin of this lagoon (Niencheski and Baumgarten, 1997).

The *El Niño* phenomenon can be considered as the main source of great pluviometric events at the South America (Ropelewski and Halpert, 1987; Grimm et al., 2000), increasing the precipitation rates in southern Brazil during the spring seasons and intensifying rains from May to July. As a consequence to the hydrographic regime inside the Patos Lagoon, the continental discharge rather exceeds its mean values (Garcia, 1997) and the water level presents a pronounced positive anomaly (Costa et al., 2003; Colling et al., 2007). In a previous study about the Patos Lagoon hydrodynamics during the 1998's *El Niño* (Fernandes et al., 2002), it was verified a great discharge increment and a raise of water level southwards the lagoon. Likewise, the period between later autumn/02 and later summer/03 was again influenced by this phenomenon (NOAA, 2006), with consequent maintenance of freshwater inside the estuarine region until the end of summer/03, as well as a mean water level higher than the decadal mean (Capítoli et al., 2008).

High rates of pluviometric precipitation in the Patos Lagoon are responsible for a considerable transport of silt and clay towards the estuarine

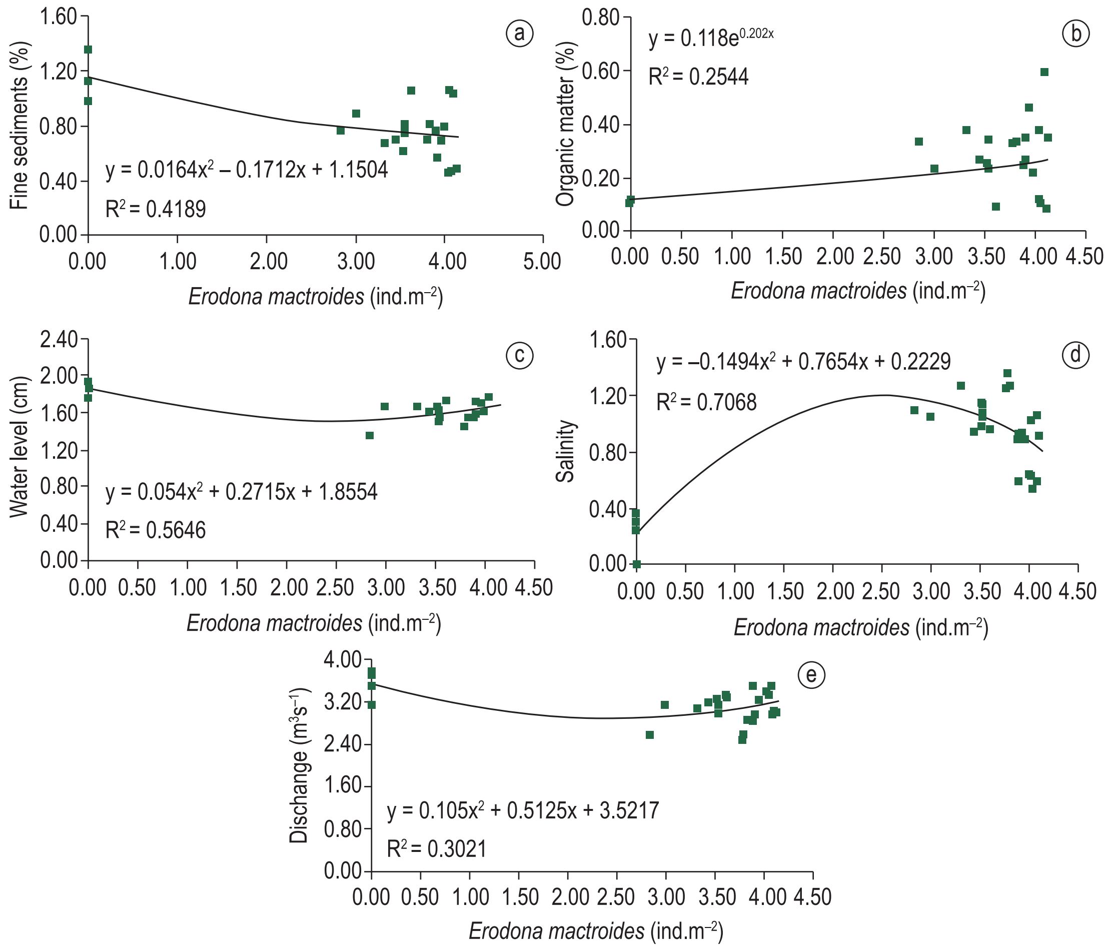

Figure 6. Regression analyses adjusted to *log* (x+1) monthly means of *Erodona mactroides* densities and the following environmental data: a) fine sediments; b) organic matter; c) water level; d) salinity; and e) water discharge.

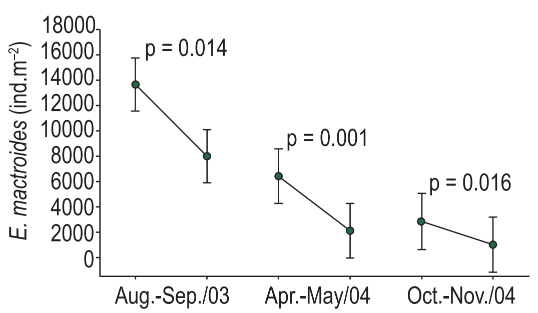

Figure 7. Decreasing *Erodona mactroides* mean densities (green points) and 95% confidence interval (lines) during the registered mortality events.

region, which come from many sources within the extensive Patos-Mirim drainage basin (Calliari, 1997). In the present work, higher percentages of fine sediments were registered in the same periods that there were observed limnetic conditions inside the southern portion of the lagoon, reinforcing the relationship between this two environmental variables.

The maintenance of limnetic conditions inside the estuarine region on summer can influence significantly the behavior of estuarine species, since in periods non influenced by the ENSO phenomenon it is expected to occur the inflow of marine water into the estuary due to low fluvial discharge (Costa et al., 1988). Changes in the ictiofaunal structure were found inside the Patos Lagoon southern portion as a consequence of the lower salinity caused by the ENSO phenomenon, being registered species from limnetic regions and reductions on marine and estuarine species' richness (Garcia et al., 2001).

Late recruitments in the macrobenthic fauna, which occurred only on later summer/03 and early autumn/03 in the Patos Lagoon estuary, evidenced that environmental changes like those on salinity, hydrodynamics and in the bottom sediments are able to influence the variability of

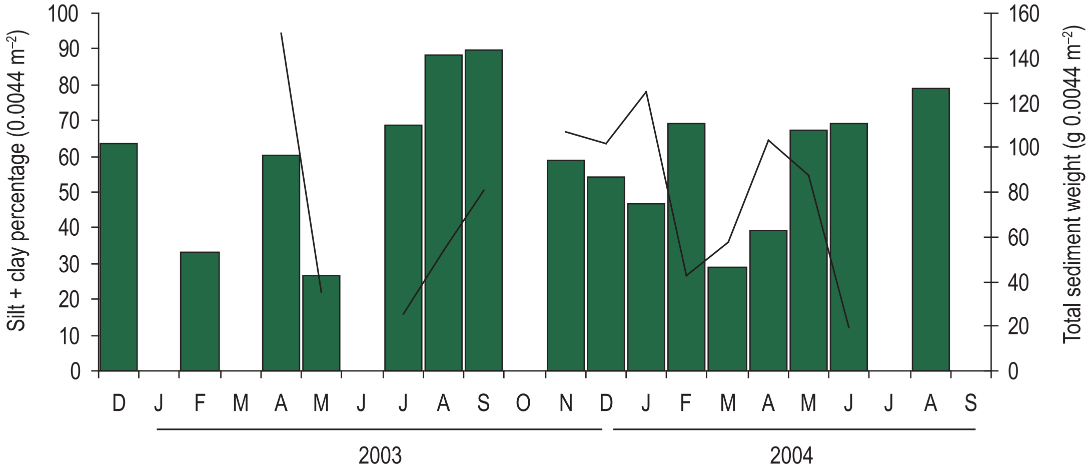

Figure 8. Silt + clay sediment percentages (green bars) and total sediment weight (black lines) monthly registered in the experiments on sediment deposition.

the macrobenthic assemblages at the shoals inside this lagoon (Colling et al., 2007). The influence of the *El Niño* anomaly was also evaluated by a long-term study concerning the temporal variability of the macrofauna from Port Curtis estuarine region (Australia), where there were registered negative consequences to the macrozoobenthic communities due to the increase of freshwater inflow towards the estuary (Currie and Small, 2005), as well as observed to the Tamar Estuary, England (Bale et al., 2006).

The beginning of *E. mactroides* recruitments were observed on later summer/03, being the first organisms found on February 2003, the same period in which it was registered the lower influence of the *El Niño* phenomenon, with increasing salinity and OM contents; and decreasing discharges, water level rates and fine sediments percentages. New recruitments (by the input of juvenile organisms) were not observed until the end of this study.

Through surveys on distribution of the macrobenthic fauna inside the Patos Lagoon, it was observed a wide spatial distribution of *E. mactroides* along the whole lagoon area and inside its southern estuarine region (Bemvenuti and Netto, 1998). This bivalve species occupies great areas in its oligohaline northern portion, where there were found at all the size classes, high density of adults (reproductive stock) and elevated biomass due to the large size of the individuals. On the other hand, only juvenile bivalves younger than one year old are registered in the southern portion, in which the species recruitment is considered potentially unsuccessful (Bemvenuti et al., 1978).

Following the freshwater discharge during the spring-summer periods, the larvae of *E. mactroides* that come from the northern region are responsible for the recruitments observed at the southern shoals (Bemvenuti and Netto, 1998), in which the success of the bivalve recruitments is found to be related to the hydrologic conditions (Bemvenuti et al., 1978, 1992).

The larval settlement registered in the present study occurred simultaneously to the environmental changes on later summer/03-autumn/03, when there were registered increments in the salinity values and decreasing percentages of fine sediments into the substrate. Taking into account that the recruitments of *E. mactroides* generally occur on spring and summer seasons, post-settled juveniles could have been experienced several displacements caused by the intense freshwater discharge in this period.

These post-settled individuals could also have been subjected to mortality events after settlement due to the *El Niño* harsh conditions, like high water discharges and elevated percentages of fine sediments. These mortality events at the initial life stages of the bivalves are not easy to detect due to their small body size and the absence of a calcified shell, characteristics that difficult their conventional sampling and accelerate their decomposition.

Greater densities of *E. mactroides* were found during autumn-winter/03 due to recruitments and consequent development of their initial life stages. From winter/03 throughout the study, there were observed successive reductions in the species densities, suggesting the existence of conditions that do not afford the persistence in time of these populations inside the estuarine region.

In a spatial-temporal evaluation concerning *E. mactroides* in Laguna Rocha (coastal region from Uruguay), it was found that the species is adapted to the continuous changes in such system, being favored by the open/close regimes of a sandy bar that separates the lagoon from the adjacent marine environment. Furthermore, the adaptability of this bivalve to colonize mixohaline environments, in which salinity values range from near zero to 20, suggests that salinity in Laguna Rocha apparently do not interfere in the spatial distribution of this species (Jorcin, 1996).

In estuarine environments, the suspended matter experience depositional processes due to the reduction in the flux velocity and flocculation of particles when in contact to salty waters (Postma, 1980; Niencheski and Windom, 1994). Regular deposition and ressuspension of fine sediments are able to result in fluid mud deposits (Allen et al., 1980), determining dynamic events on the shallow estuarine bottoms that can directly interfere in the development of macrobenthic species (Ysebaert and Herman, 2002; Teske and Wooldridge, 2003; Thrush et al., 2003) and sub-superficial bivalves like *E. mactroides*. Mortality events were previously observed in the Patos Lagoon estuarine shoals after *E. mactroides* recruitments (Bemvenuti et al., 1978; Bemvenuti and Netto, 1998), being suggested the relationship between mortality and deposition of fine sediments at shallow embayments (Bemvenuti, 1997a), besides not quantified. The mortality events registered in the present work on August-September 2003, April-May 2004 and October-November 2004 evidenced the occurrence of adverse conditions to the species development at the shoals in the southern estuarine portion. Simultaneously to the mortality events, the quantification of depositional events evidenced that the input of fine sediments (silt + clay) in the substrate interferes negatively on the bivalves' survival.

The winter/03 was also marked by a pronounced salinity variation inside the estuarine region, with fortnightly means ranging from near zero to 10 during short periods. Periods of freshwater discharge associated with marine water inflows induced by S winds cause a vertical stratification which results in a saltwedge formation (Niencheski and Baumgarten, 1997). Furthermore, the interactions between the geomorphologic features of the estuary in its southern portion and the penetration of marine water during strong S winds, can both favor the ressuspension of fine sediments deposited inside the estuarine area (Niencheski and Windom, 1994; Niencheski and Baumgarten, 1997).

Instability at the bottom's surface can also be a cause of stress to suspension feeder bivalves due to post-settled larvae ressuspension, burying and/or recruitment suppression (Rhoads and Young, 1970). Moreover, suspension feeder organisms are sensible to intense silt and clay depositions, presenting then severe mortality (Levinton, 1995). In this sense, short-siphon bivalves like *E. mactroides* are also susceptible to massive mortalities due to the clogging of their filter-feeding apparatus, like previously observed for the bivalve *Rangia cuneata* Sowerby, 1831 (Peddicord, 1977). Field experiments on adults of *R. cuneata* have shown that mortality was higher and growth was slower for those individuals on fine sediments than for those growing on sandy substrate (Tenore, 1968). Furthermore, the growth of *R. cuneata* adults was faster in clams placed in sand than those in mud (Peddicord, 1976), evidencing a great recruitment success associated to coarse sediments.

This work showed that the input of juveniles into the southern estuary, which depends of the discharge regime from its upper portion, characterizes the recruitments of *E. mactroides* as temporally unpredictable southwards. The present evaluation concerning the interactions between the species temporal variability and the hydrologic characteristics of the estuarine region give support to understand the dynamic from one of the major macrobenthic components, evidencing the species relationship to small-scale environmental parameters and global events of low predictability like *El Niño* phenomenon. Moreover, mortality events and substrate dynamics were found to be linked, evidencing that fine deposition processes can interfere in the recruitment success and temporal persistence of *E. mactroides* at shoals inside estuarine regions.

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References

ALLEN, GP., SALOMON, JC., BASSOULET, P., Du PENHOAT, Y. and De GRANDPRÉ, C. 1980. Effects of tides on mixing and suspended sediment transport in macrotidal estuaries. *Sedimentary Geology*, vol. 26, p. 69-90. http://dx.doi.org/10.1016/0037-0738(80)90006-8

ARAÚJO, FJ. 1984. Hábitos alimentares de três espécies de bagres marinhos (Ariidae) no estuário da Lagoa dos Patos, RS, Brasil. *Atlântica*, vol. 7, p. 47-63.

ASMUS, M. 1997. Coastal plain and Patos Lagoon. In SEELIGER, U., ODEBRECTH, C. and CASTELLO, JP., eds. *Subtropical Convergence Environments - The Coast and Sea in the Southwestern Atlantic*. Berlin Heidelberg: Springer-Verlag. p. 9-13.

BALE, AJ., WIDDOWS, J., HARRIS JB. and STEPHENS, JA. 2006. Measurements of the critical erosion threshold of surface sediments along the Tamar Estuary using a mini-annular flume. *Continental Shelf Research*, vol. 26, p. 1206-1216. http://dx.doi.org/10.1016/j.csr.2006.04.003

BEMVENUTI, CE. 1997a. Trophic Structure. In SEELIGER, U., ODEBRECTH, C. and CASTELLO, JP., eds. *Subtropical Convergence Environments - The Coast and Sea in the Southwestern Atlantic*. Berlin Heidelberg: Springer-Verlag. p. 70-73.

BEMVENUTI, CE. 1997b. Benthic Invertebrates. In SEELIGER, U., ODEBRECTH, C. and CASTELLO, JP., eds. *Subtropical Convergence Environments - The Coast and Sea in the Southwestern Atlantic*. Berlin Heidelberg: Springer-Verlag. p. 43-47.

BEMVENUTI, CE., CAPÍTOLI, RR. and GIANUCA, NM. 1978. Estudos de ecologia bentônica na região estuarial da Lagoa dos Patos. II. Distribuição quantitativa do macrobentos infralitoral. *Atlântica*, vol. 3, p. 23-32.

BEMVENUTI, CE., CATTANEO, SA. and NETTO, SA. 1992. Características estruturais da macrofauna bentônica em dois pontos da região estuarial da Lagoa dos Patos, RS - Brasil. *Atlântica*, vol. 14, p. 5-28.

BEMVENUTI, CE. and NETTO, SA. 1998. Distribution and seasonal patterns of the sublittoral benthic macrofauna os Patos Lagoon (South Brazil). *Revista Brasileira de Biologia*, vol. 58, p. 211-221.

CALLIARI, LJ. 1997. Environment and biota of the Patos Lagoon Estuary. In SEELIGER, U., ODEBRECTH, C. and CASTELLO, JP., eds. *Subtropical Convergence Environments - The Coast and Sea in the Southwestern Atlantic*. Berlin Heidelberg: Springer-Verlag. p. 13-14.

CAPÍTOLI, RR., BEMVENUTI, CE. and GIANUCA, NM. 1978. Estudos de ecologia bentônica na região estuarial da Lagoa dos Patos, I. Comunidades bentônicas. *Atlantica*, vol. 3, p. 5-21.

CAPÍTOLI, RR., COLLING, LA. and BEMVENUTI, CE. 2008. Cenários de distribuição do mexilhão dourado *Limnoperna fortunei* (MOLLUSCA-BIVALVIA) sob distintas condições de salinidade no complexo lagunar Patos-Mirim, RS - Brasil. *Atlântica*, vol. 30, p. 35-44.

CARCELLES, A. 1941. "*Erodona mactroides*" en el Rio de la Plata. *Physis,* vol. 19, p. 11-21.

CLARKE, KR. and WARWICK, RM. 1994. *Changes in marine communities*: an approach to statistical analysis and interpretation. Plymouth: Natural Environmetal Research Council.

CLOSS, D. 1962. Foraminíferos e tecamebas da Lagoa dos Patos. *Boletim da Escola de. Geologia de Porto Alegre*, vol. 11, p. 1-130.

COLLING, LA., BEMVENUTI, CE. and GANDRA, MS. 2007. Seasonal variability on the structure of sublittoral macrozoobenthic association in the Patos Lagoon estuary, southern Brazil. *Iheringia, Série Zoologia*, vol. 97, p. 257-263.

COSTA, CMB. 1971. Importância paleoecológica e estratigráfica de *Erodona mactroides* Daudin (Mollusca, Bivlavia). *Iheringia, Serie geologia*, vol. 4, p. 3-18.

COSTA, CSB., MARANGONI, JC. and AZEVEDO, AMG. 2003. Plant zonation in irregularly flooded salt marshes: relative importance of stress tolerance and biological interactions. *Journal of Ecology*, vol. 91, p. 951-965. http://dx.doi.org/10.1046/j.1365-2745.2003.00821.x

COSTA, CSB., SEELIGER, U. and KINAS, PG. 1988. The effect of wind velocity and direction on the salinity regime in the Patos Lagoon estuary. *Ciência e Cultura*, vol. 40, p. 909-912.

CURRIE, DR. and SMALL, KJ. 2005. Macrobenthic community responses to long-term environmental change in an east Australian sub-tropical estuary. *Estuarine, Coastal and Shelf Science*, vol. 63, p. 315-331. http://dx.doi.org/10.1016/j.ecss.2004.11.023

DAVIES, BE. Loss-on-ignition as an estimate of soil organic matter. *Soil Science Society of America Journal*, 1974, vol. 38, p. 150-151. http://dx.doi.org/10.2136/sssaj1974.03615995003800010046x

FERNANDES, EHL., DYER, KR., MÖLLER, OO. and NIENCHESKI, LFH. 2002. The Patos Lagoon Hydrodynamics during *El Niño* event (1998). *Coastal and Shelf Research*, vol. 22, p. 1699-1713.

GARCIA, CAE. 1997. Hydrographic Characteristics. In SEELIGER, U., ODEBRECTH, C. and CASTELLO, JP., eds. *Subtropical Convergence Environments - The Coast and Sea in the Southwestern Atlantic*. Berlin Heidelberg: Springer-Verlag. p. 18-20.

GARCIA, AM., VIEIRA, JP. and WINEMILLER, KO. 2001. Dynamics of the shallow-water fish assemblage of the Patos Lagoon estuary (Brazil) during cold and warm ENSO episodes. *J. Fish Biol.*, vol. 59, p. 1218-1238. http://dx.doi.org/10.1111/j.1095-8649.2001.tb00187.x

GERALDI, RM. 2002. *Distribuição especial, recrutamento, crescimento e mortalidade de Erodona mactroides BOSC, 1802 (MOLLUSCA, PELECYPODA) na Lagoa dos Patos, RS - Brasil.* Rio Grande: Universidade

Federal do Rio Grande. [Tese de Doutorado em Oceanografia Biológica].

GRIMM, AM., BARROS, VR., and DOYLE, ME. 2000. Climate variability in Southern South America associated with *El Niño* and *La Niña* events. *Journal of Climate*, vol. 1, p. 35-38.

JORCIN, A. 1996. Distribucion, abundancia y biomasa de *Erodona mactroides* DAUDIN 1801 (Mollusca, Bivalvia), en la Laguna de Rocha (Dpto. De Rocha, Uruguay). *Revista Brasileiro de Biologia*, vol. 56, p. 155-162.

KJERFVE, B. 1986. Comparative oceanography of coastal lagoons. In WOLFE, DA., ed. Estuarine variability. Orlando: Academic Press. p. 63-81.

LEVINTON, JS. 1995. *Marine Biology*: function, biodiversity, ecology. Oxford: Oxford University Press.

MUNIZ, P. and VENTURINI, N. 2001. Spatial distribution of the macrozoobenthos in the Solís Grande stream estuary (Canelones-Maldonado, Uruguay). *Brazilian Journal of Biology,* vol. 61(3), p. 409-420. http://dx.doi.org/10.1590/S1519-69842001000300010

NIENCHESKI, LFH. and BAUMGARTEN, MGZ. 1997. Environmental Chemistry. In SEELIGER, U., ODEBRECHT, C. and CASTELLO, JP., ed. *Subtropical Convergence Environments - The Coast and Sea in the Southwestern Atlantic*. Berlin Heidelberg: Springer-Verlag. p. 20-24.

NIENCHESKI, LFH. and WINDOM, HL. 1994. Nutrient flux and budget in Patos Lagoon Estuary. *Science of the Total Environment*, vol. 149, p. 53-60. http://dx.doi.org/10.1016/0048-9697(94)90004-3

National Oceanic and Atmospheric Administration - NOAA. 2006. Available from: <http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml>. Access in: 6 jan. 2007.

PASSADORE, C., GIMÉNEZ, L. and ACUÑA, A. 2007. Composition and intra-annual variation of the macroinfauna in the estuarine zone of the Pando Stream (Uruguay). *Brazilian Journal of Biology*, vol. 67, no. 2, p. 197-202. http://dx.doi.org/10.1590/S1519-69842007000200003

PEDDICORD, RK. 1976. Effects of substratum on growth of the bivalve *Rangia cuneata* Gray, 1831. *Veliger*, vol. 18, p. 398-404.

PEDDICORD, RK. 1977. Salinity and substratum effects on condition index of the bivalve *Rangia cuneata*. *Marine Biology*, vol. 39, p. 351-360. http://dx.doi.org/10.1007/BF00391938

POSTMA, H. 1980. Sediment transport and sedimentation. In OLAUSSON, E. and CATO, I., ed. *Chemistry and biogeochemistry of estuaries*. Chichester: Wiley. p. 153-186.

RHOADS, DC. and YOUNG, DK. 1970. The influence of deposit-feeding organisms on sediment stability and community trophic structure. *Journal of Marine Research*, vol. 28, p. 150-178.

RIOS, E. 2009. *Compendium of Brazilian seashells*. Porto Alegre: Evangraf. 668 p.

ROPELEWSKI, CF. and HALPERT, MS. 1987. Global and Regional scale precipitation patterns associated with *El Niño*/ Southern Oscillation. *Monthly Weather Review*, vol. 115, p. 1606-1626.

ROSA-FILHO, JS. and BEMVENUTI, CE. 1998. Caracterización de las comunidades macrobentónicas de fondos blandos en regiones estuarinas de Rio Grande do Sul (Brasil). *Thalassas*, vol. 18, p. 43-56.

ROSA, LC. and BEMVENUTI, CE. 2007. Seria a macrofauna bentônica de fundos não consolidados influenciada pelo aumento a complexidade estrutura do habitat? O caso do estuário da Lagoa dos Patos. *Brazilian Journal of Aquatic Science and Technology*, vol. 11, no. 1, p. 51-56.

SUGUIO, K. 1973. *Introdução à sedimentologi*a. São Paulo: EDUSP.

TENORE, KR., HORTON, DB. and DUKE, TW. 1968. Effects of bottom substrate on the brackish water bivalve *Rangia cuneata*. *Chesapeake Science*, vol. 9, p. 238-248. http://dx.doi.org/10.2307/1351314

TESKE, P. and WOOLDRIDGE, T. 2003. What limits the distribution of subtidal macrobenthos in permanently open and temporally open/closed South African estuaries? Salinity vs. sediment particle size. *Estuarine, Coastal and Shelf Science,* vol. 57, p. 225-238. http://dx.doi.org/10.1016/S0272-7714(02)00347-5

THRUSH, S., HEWITT, J., NORKKO, A., NICHOLLS, P., FUNNELL, G. and ELLIS, J. 2003. Habitat change in estuaries: predicting broad-scale responses of intertidal macroinfauna to sediment mud content. *Marine Ecology Progress Series*, vol. 263, p.101-112. http://dx.doi.org/10.3354/meps263101

VAZ, AC., MÖLLER JUNIOR, OO. and ALMEIDA, TL. 2006. Análise quantitativa da descarga dos rios afluentes da Lagoa dos Patos. *Atlântica*, vol, 28, no. 1, p. 13-23.

Von IHERING, HFA. 1885. Die Lagoa dos Patos. *Deutsche Geographische Blatter*, vol. 2, p. 164-203.

YSEBAERT, T. and HERMAN, P. 2002. Spatial and temporal variation in benthic macroinfauna and relationships with environmental variables in an estuarine, intertidal sofr-sediment environmental. *Marine Ecology Progress Series*, vol 244, 105-124. http://dx.doi.org/10.3354/meps244105

ZAR, JH. 1984. *Biostatistical analysis*. Englewood Cliffs: Prentice-Hall Inc. 718 p.

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