CICIMAR Oceánides 30(1): 9-20 (2015)

MACROBENTHIC COMMUNITIES IN A TEMPERATE URBAN ESTUARY OF HIGH DOMINANCE AND LOW DIVERSITY: MONTEVIDEO BAY (URUGUAY)

Muniz, P. & N. Venturini

Sección Oceanografía y Ecología Marina, Facultad de Ciencias. Iguá 4225, Montevideo 11400-Uruguay. email: pmmaciel@fcien.edu.uy

ABSTRACT. The macrobenthic subtidal community was studied between April 1997 and April 1998 in Montevideo bay, an urban estuary located in the fluvio marine system of the Río de la Plata (Uruguay) that receives a variety of industrial and sewage inputs. Monthly surveys were carried out at ten sampling stations where sediment samples were taken with a manual corer and analysed for granulometric parameters, organic matter content, chlorophyll *a* and phaeopigments content, redox potential, and macrobenthic fauna. The area presented high organic matter content in its sediments and several regions of the bottom were anoxic during a large part of the sampling period. The benthic macrofauna was dominated, both in numbers as well as in biomass, by the small surface deposit-feeder gastropod *Heleobia* cf. *australis*. Cluster analysis, Multidimensional Scaling and Canonical Correspondence Analysis revealed that the study area could be divided in two well-defined regions with different environmental characteristics and different faunal composition. The dissolved oxygen content in the bottom water and variables related to it were the most important factors in explaining the patterns of the benthic communities. At the phylum level, the meta-analysis of "production" showed a high disturbance status for all stations. The inner region, the most affected by anthropogenic activities, was the most compromised environmentally and biologically, and was characterised by a very low diversity and abundance, reduced conditions in the sediments and low oxygenated bottom water. In more external places of the bay, on the other hand, perhaps due to their location at a greater distance from the sources of organic material and in a region with higher hydrodynamic energy, the conditions for the development of benthic fauna were more favourable. Spatial and temporal faunistic patterns observed and their possible causes are analysed and discussed in relation to the natural and anthropogenic factors that act in this coastal ecosystem.

Keywords: Macrobenthic communities, soft-bottom, estuary, Montevideo bay, Río de la Plata.5

Comunidades macrobentónicas en un estuario urbano templado de alta dominancia y baja diversidad: Bahía de Montevideo (Uruguay)

RESUMEN. Una comunidad macrobentónica submareal fue estudiada entre abril de 1997 y abril de 1998 en la Bahía de Montevideo, un estuario urbano localizado en el sistema marino fluvial del Río de la Plata (Uruguay) que recibe una variedad de descargas industriales y de alcantarillado. Se llevaron a cabo muestreos mensuales en diez estaciones donde se tomaron muestras de sedimento utilizando un nucleador y a estas les fueron analizadas los parámetros granulométricos, el contenido de materia orgánica, el contenido de clorofila *a* y de feopigmentos, potencial redox y fauna macrobentónica. El área presentó un alto contenido de materia orgánica en sus sedimentos y muchas regiones del fondo mostraron ser anóxicas durante una gran parte del mismo período. La fauna macrobentónica fue dominada en número y biomasa por los pequeños gasterópodos *Heleobia* cf. *australis*. Los análisis de conglomerados, de escala multidimensional y de correspondencia canónica revelaron que el área de estudio podría ser dividida en dos regiones bien definidas con diferentes características ambientales y composiciones faunísticas diferentes. El contenido de oxígeno disuelto en agua de fondo y las variables realcionadas con ella fueron los factores más importatntes en explicar los patrones de las comunidades bentónicas. Al nivel phylum, los meta análisis de la "producción" mostraron un alto estatus de perturbación y biológica que fue caracterizada por baja diversidad y abundancia, condiciones reducidas y agua de fondo poco oxigenada. Por otra parte, en los sitios más externos de la bahía, debido quizas a su localización a una gran distancia de las fuentes de materia orgánica con una alta energía hidrodinámica, las condiciones para el desarrollo de la fauna bentónica fueron favorables. Los patrones faunísticos espaciales y temporales observados y sus posibles causas fueron analizados y discutidos en relación con los factores naturales y antropogénicos que actúan sobre este ecosistema costero.

Palabras Clave: comunidades macrobentónicas, fondos blandos, estuarios, Bahía de Montevideo, Río de la Plata.

Muniz, P. & N. Venturini. 2015. Macrobenthic communities in a temperate urban estuary of high dominance and low diversity: Montevideo bay (Uruguay). *CICIMAR Oceánides*, 30(1): 9-20.

INTRODUCTION

In recent years the ecological integrity of many estuarine and coastal systems has been stressed by activities of growing human populations and associated land use. These stresses are usually expressed through a broad category of responses that are termed eutrophication and are associated with excess production of organic matter (Rosenberg, 1985) and the consequent deficiency of dissolved oxygen in the bottom waters.

The effects of point source discharges on the structure and composition of nearshore benthic macroinvertebrate fauna has been well documented and extensively reviewed (e.g. Pearson & Rosenberg, 1978; Warwick, 1988). Studies to determine the effects of diffuse pollution in estuaries are often complicated by the presence of inputs of different composition from multiple sources, and discharge to

Fecha de recepción: 28 de enero de 2015 Fecha de aceptación: 17 de marzo de 2015

an area of naturally variable physico-chemical conditions, with the consequent loss of pollutant and effect gradients. It is necessary to evaluate the condition of such estuaries to determine areas of concern and establish effective and economical monitoring systems to record the effects of pollution on the fauna.

Benthic organisms are used extensively as indicators of estuarine environmental status and trends, due to numerous studies which have demonstrated that they respond predictably to many kinds of natural and human induced stress (López-Jamar, 1985; Dauer, 1993; **among others** Ritter & Montagna, 1999). Many characteristics of benthic associations make them useful indicators. Exposure to hypoxia is typically greatest in near-bottom waters and anthropogenic contaminants often accumulate in sediments where benthos lives. The limited mobility of the majority of adult macrobenthic organisms has advantages in environmental assessment because, unlike most pelagic fauna, their assemblages reflect local environmental conditions (Gray, 1979; Muniz *et al.*, 2013).

Benthic communities are part of any marine ecosystem, and the analysis of their structure is an important tool to describe changes in space (with application to point source pollution monitoring) and time (with application to the description of changes in the state of the marine system) (Heip, 1992). Although such coastal systems in temperate and high latitudes are well described (Pires, 1992), the Uruguayan coastal zone is poorly understood and studies describing the soft-bottom benthic subtidal system are scarce (Scarabino *et al.*, 1975; Demichelli, 1984; 1986; Venturini *et al.*, 2004; Muniz *et al.*, 2011).

Montevideo bay is an urban estuary in Uruguay receiving a variety of industrial and sewage inputs (Muniz *et al.*, 2002; 2004; Muniz & Venturini, 2011, García Rodríguez *et al.*, 2010; Venturni *et al.*, 2012; 2015). The present results are part of an integrated program designed to determine the effects of the different pollutant sources on the aquatic biota and to establish effective and economical monitoring systems. It describes, for the first time, the temporal-spatial structure of the macrobenthic subtidal communities over one year of study. Although some new and important advances were developed since the sampling campaigns of the present study, these results are new and important for the knowledge of the studied system.

MATERIAL AND METHODS

Study area

Montevideo bay (Figure 1) is located in the fluvio marine system of the Río de la Plata, (Montevideo, Uruguay) between 34º52'-34º56' S and 56º10'-56º15' W, and has an approximate area of 10 km^2 and a mean depth of 5 m. Three streams flow into it, the Miguelete Stream, the Pantanoso Stream and the Seco Stream which flows through a pipe. These streams carry wastes of many different industries and urban centres, as well from a great number of sewage pipes**.** The bay also harbours the ANCAP refinery, the Batlle steam water plant (UTE) and an active port: The Port of Montevideo. The Bay is protected from the South winds, which are infrequent but very strong, by two breakwaters built at the beginning of the century: the Sarandí breakwater and the Oeste breakwater. The entrance to the port is a channel 9.3 km long and the port's main structures are in the southern area. There is a special dock (La Teja Dock) where oil tankers load and unload, in the northern area between the mouths of the Pantanoso and Miguelete Streams. This dock communicates with the outer anchorage by a channel 9 m deep.

The bay has a great importance not only for the city, but also for the whole country. Even though its principal use is as the physical structure supporting the Port of Montevideo, there are other uses associated with it: activities pertaining to the port (those related to the piers, dockyards, warehouses etc.), as a water source for cooling of industrial processes (UTE and ANCAP), rowing, recreational fishing, sailing and other secondary uses. At present, it is not possible to use the bay for recreational activities that involve direct contact with the water, mainly due to the input of wastes coming from the streams and the sewage pipes that drain directly into the bay.

Predominant winds are from NE and W-SW, being very important in determining water circulation at low depths (Moresco & Dol, 1996), which is mainly clock-wise.

Data collection and laboratory methods

Monthly surveys were carried out from April 1997 to April 1998 at ten sampling stations distributed across the Bay according to the oxygen content in the bottom water (Figure 1).

At each station, 14 replicate sediment samples were taken with a manual corer of 4.5 cm of internal diameter. Of them, 10 replicates were washed through a 0.4 mm sieve mesh and the material retained was preserved in 70% ethanol for the quantitative analysis of the benthic macrofauna. The sorting and identification were made under a stereoscopic microscope. Then the biomass was estimated by means of dry weight (70º C until constant weight) for individual species. Also 10 minutes dredging at 2 knots constant velocity was done at each station. This did not detect important differences in species richness and therefore for this paper these data are

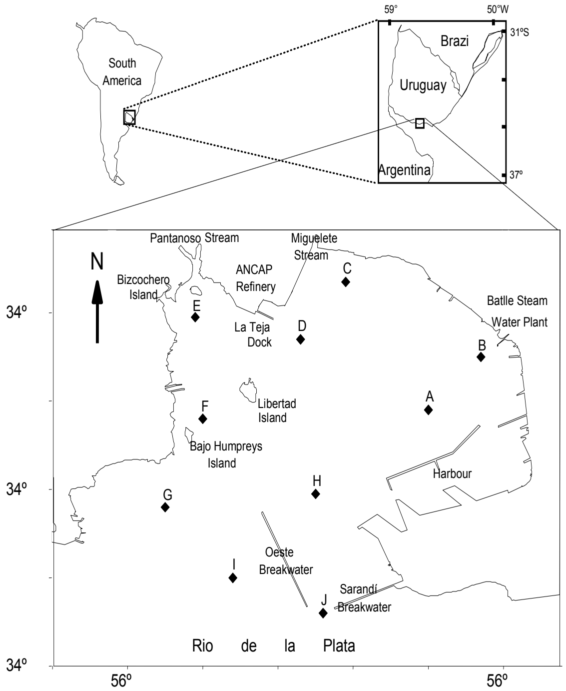

Figure 1. Map of Montevideo bay and region with the 10 sampling stations (black diamonds).

not presented.

Nearly 100 g of the first of the other four replicates of the corer sediment samples were submitted to the standard dry-sieve and pipette method (Suguio, 1973) and parameters described by Folk & Ward (1957) were calculated for sedimentological data. The second replicate was used to determine the photosynthetic pigments of surface sediment according to Lorenzen (1967). With the third replicate we determined the redox potential of the sediment column using the standard solution (buffer) of Zobell (1946). The last corer sample was used to obtain the organic matter content of the surface sediment by means of the calcination technique according to Byers *et al.* (1978).

Bottom water samples were obtained with "Hydro-Bios" bottles to measure temperature and determine dissolved oxygen content by the Winkler titration method according to Grasshoff (1983). With a "YSI" multi-parameter salinity and pH were determined and the depth was measured with a "Humminbird" echo-sounder.

Data analysis

Univariate and multivariate methods (classification and ordination) were used. The former included: density as number of individuals per unit area, abundance of individuals per species and species richness per unit area for each month. Diversity was estimated by the Shannon-Wiener index (Shannon & Weaver, 1963) using natural logarithms, and evenness with Pielou's index (1975).

In order to define groups of stations with similar attributes according to species abundance and biomass, an agglomerative classification analysis in "Q mode" was performed. The similarity matrix was constructed using the Bray-Curtis similarity index (Bray & Curtis, 1957) and grouped by the Unweighted Pair-Group Method using arithmetic Averages (UPGMA) (Romesburg, 1984). The 4th root transformation was used to reduce contributions to similarity by abundant species, and therefore to increase the importance of the less abundant species in the analyses.

n-MDS ordinations (Kruskal & Wish, 1978) using the same similarity matrices were undertaken to complement the classification analyses.

Species data were also aggregated into phyla and combined to produce a production matrix according to the formula suggested by Warwick & Clarke (1993), $P = (B/A)^{0.73} \times A$, where A is the abundance and B the biomass. This matrix was made with the 50 standard sites used by these authors and included the 10 sample sites of Montevideo Bay.

The relationships between multivariate community structure and environmental variables considered in this study were examined using the BIO-ENV procedure with Spearman's weighted coefficient of correlation (Clarke & Ainsworth, 1993). This procedure determines the combination of variables that "best" explain the observed biological patterns, according to the level of correlation between the biotic matrix's ranking of similarity and the abiotic matrix's ranking of similarity. The environmental similarity matrix was calculated using the normalised Euclidean Distance, that is, before distances were calculated data were normalised as $(x-\mu)/\sigma$, which consists of subtracting from each value (x) the mean value (μ) and dividing by the standard deviation (σ). This homogenises the variables and solves the problem of different scales and units that they have. The biotic similarity matrix was the same as that used in the classification and ordination analyses. All the above statistical analyses were carried out with the PRIMER software package. A Canonical Correspondence Analysis (CCA) was also applied to the same biological and environmental data using the CANOCO program (ter Braak, 1986; 1988). This makes more restrictive assumptions about the form of the data and the inter-relationships between biological and environmental data but makes for an interesting comparison of techniques. Also it allows the species to be arranged on an environmental basis, offering in a single diagram the direct interpretation of possible relationships between species, stations and environmental variables (Nielsen & Hopkins, 1992). The environmental variables were selected through the forward option in the CANOCO program. The relationship between the species and environmental variables was tested by the Monte-Carlo permutation test (ter Braak, 1990).

RESULTS

Environmental conditions

In Montevideo bay the organic matter content of the surface sediment was higher than in other estuaries of other regions (e.g. Seys *et al.*, 1994; Ieno & Bastida, 1998) and was spatially as well as temporally very variable. The concentrations of chlorophyll *a* and phaeopigments were lower but very variable throughout the study area, with the highest contents occurring generally at the shallowest stations. Bottom water was alkaline and pH did not show great variations (Table 1).

Spatially the results showed that Montevideo bay could be divided in two regions. Stations A, B, C, D and E (inner region) were characterised by their relative shallowness, higher temperature and lower salinity than the rest of the stations. In addition to this, they presented very low bottom oxygen concentrations (Table 1 and Table 2) and the highest chlorophyll *a* concentrations in superficial sediments. The results of the redox analysis showed that this area of the bay always displayed reduced conditions in the water-sediment interface. These stations also showed the highest percentage of organic matter except C and E. These stations possessed low organic matter content but an organic matter/clay ratio similar to that of stations A, B and D. Stations A, B and D were dominated by the silt-clay fraction while C and E, had a higher contribution of sand, reaching an annual mean of 65.38 % and 70.12 % respectively.

The outer region of the bay, comprising stations F, G, H, I and J, was characterised by a greater depth, higher bottom salinity and higher bottom dissolved oxygen content than the inner region. The chlorophyll *a* content of the superficial sediments was lower. Stations H and J were situated in the access channels to the Montevideo Port, which are frequently dredged. The organic matter content was lower here than in the inner region but Sts F, G and I presented the lowest values in the study area. The silt-clay fraction was the predominant one.

The fauna

The total mean abundance determined was of 30118 individuals belonging to the Phyla Arthropoda, Nematoda, Mollusca and Annelida. Because of their abundance and high frequency of occurrence *Heleobia* cf. *australis*, *Nephtys fluviatilis*, *Erodona mactroides*, *Heteromastus similis*, and *Alitta succinea* stand out, as well as unidentified Nematode and Ostracode (Table 3).

Density was very variable at each station monthly. Overall, stations the highest values occurred in May, June and July 1997 and the lowest in March 1998 (Figure 2a). In general, stations B, C and D presented a lower number of individuals per unit area than the remaining stations. Ignoring unidentified nematodes, ostracods and barnacles a total of 9 species were recorded. Maximum species richness occurred between April and August 1997

Table 1. Environmental variables measured in the Montevideo Bay. Values are annual means +- one standard deviation (SD).

Sts		Depth (m)	T (ºC)	Sal (psu)	O_2 (mg/L)	pH	Chlor *a* (mg/m^2)	%OM	Eh (mV)	%sand	%silt	%clay	Md(mm)
A	Mean	1,82	18,87	5,44	2,80	7,22	10,97	7,77	177,33	18,71	68,82	12,47	0,036
	SD	0,49	4,66	3,69	0,75	0,53	4,32	2,46	119,79	9,84	10,93	7,48	0,01
B	Mean	2,34	18,83	6,72	1,18	7,23	9,64	9,50	92,33	18,44	57,81	23,84	0,032
	SD	0,87	4,36	4,18	0,53	0,21	10,03	3,16	73,48	10,69	21,56	16,25	0,02
C	Mean	1,46	19,46	5,05	2,95	7,26	33,68	3,36	147,75	65,38	26,25	8,374	0,185
	SD	0,33	4,54	3,49	1,42	0,20	27,87	3,93	84,83	38,49	30,22	13,85	0,14
D	Mean	4,66	17,22	10,36	1,55	7,37	15,38	11,17	113,29	12,80	64,01	23,19	0,033
	SD	0,90	4,16	6,28	1,36	0,35	4,52	1,52	47,82	12,30	11,68	12,55	0,02
E	Mean	1,64	18,70	4,45	3,88	7,37	8,40	5,21	179,00	70,12	26,04	3,874	0,134
	SD	0,32	4,22	1,96	1,45	0,21	5,38	6,89	103,87	21,13	19,84	2,17	0,09
F	Mean	3,39	17,67	5,44	7,04	7,49	8,42	5,50	229,00	26,23	64,04	9,72	0,030
	SD	0,95	4,29	2,42	2,12	0,19	7,26	1,97	89,28	9,61	15,38	8,52	0,01
G	Mean	4,48	17,51	6,11	8,16	7,61	3,91	6,36	189,00	17,85	71,40	10,75	0,036
	SD	0,70	4,30	5,46	1,62	0,23	3,10	2,01	62,65	26,18	23,82	5,67	0,04
H	Mean	5,59	17,28	10,80	6,49	7,50	5,93	7,95	199,00	4,46	79,49	16,05	0,023
	SD	0,74	4,29	6,35	1,70	0,20	3,98	2,45	58,55	1,49	5,12	4,75	0,00
I	Mean	6,00	16,81	12,80	6,55	7,54	3,88	5,62	184,00	15,15	72,31	12,54	0,022
	SD	0,63	3,87	7,82	1,31	0,33	3,57	2,03	76,95	9,37	12,31	10,90	0,01
J	Mean	9,91	16,59	14,79	6,64	7,67	7,58	7,33	210,11	5,92	78,78	15,30	0,038
	SD	1,59	3,71	8,64	1,76	0,26	6,74	2,32	61,43	6,25	9,99	8,32	0,06

Table 2. Hypoxia events registered at the bay during the study period.

Station	Date	OD (mg/l)
B	05- 97	0.09
B	06- 97	1.45
B	07- 97	0.36
B	08- 97	0.45
D	09- 97	0.01
C	10- 97	0.88
C	12- 97	1.31
C	01- 98	1.84
B	02- 98	1.56
C	04- 98	0.62
D	04- 98	1.22

(Figure 2b). Stations F and G showed the highest species richness, and the lowest values were found at stations B, C and D. Species richness was low throughout the study. A higher number of individuals did not always correspond to a higher number of species.

Shannon's diversity was also very low, reflecting the high dominance of *Heleobia* cf. *australis*, a

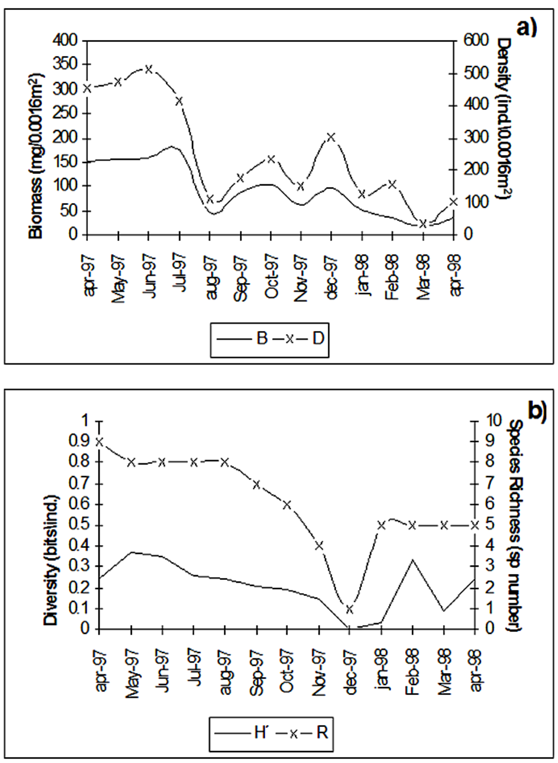

Figure 2. a) Mean monthly values of density and biomass of macrobenthic fauna for Montevideo bay. b) Mean monthly values of diversity and species richness of macrobenthic fauna for Montevideo Bay.

Table 3. Frequency of occurrence of macrobenthic species and groups recorded in Montevideo Bay and mean density (ind.\0.0016 m^2) of each one during the sampling period. Between () are assigned the species code for the figure 5.

Organisms	Frequency (%)	Mean density
Nematoda (1)	36.15	7
Polychaeta		
Neanthes succinea (2)	6.92	2
Nephtys fluviatilis (3)	26.92	3
Heteromastus similis (4)	20	2
Goniadides sp. (5)	1.53	1
Glycera sp. (6)	0.76	1
Sigambra cf. *grubii* (7)	0.76	1
Gasteropoda		
Heleobia cf. *australis* (8)	85.38	218
Bivalvia		
Erodona mactroides (9)	25.38	4
Ostracoda (10)	12.3	3
Isopoda (11)	4.61	1
Balanus (12)	0.76	1

very small gastropod that occurs frequently at very high abundance in several regions of the bay. The maximum diversity was registered in September 1997 at station G (1.63) and the minimum at station B (0) where only nematodes were present. Between April and August 1997 the highest diversity values were registered in the majority of the sampling stations. In November of the same year diversity decreased notably and in February 1998 it increased again (Figure2b).

As for abundance, biomass was also variable in all stations during the period of study. The highest biomass values of the dominant species *Heleobia* cf. *australis* were occasionally exceeded by those corresponding to the second most abundant species, the bivalve *Erodona mactroides*. The highest biomass value was recorded in July 1997 and the lowest in March 1998 (Figure 2a).

Multivariate analyses

Cluster analysis of abundance and biomass data (annual arithmetic mean of pooled data) showed two groups of stations at approximately 60% of similarity (Figure 3). One group was composed of the most-inner stations B, C and D, and the remaining stations constituted the other. The same two groups appeared in the n-MDS ordinations (Figure 3).

The meta-analysis (Figure 4) showed that stations of Montevideo bay appeared grouped at the right end of the diagram, that is to say, at the end of the pollution gradient showed and described by Warwick & Clarke (1993b). Table 4 presents the data set of Montevideo Bay used to perform the meta-analysis; these data were added to table ´2´ of Warwick & Clarke (1993).

BIO-ENV results for all data pooled showed that the environmental variable that "best" explains the structure of this benthic community is dissolved oxygen concentration of bottom water (OD) with a correlation coefficient of 0.667 (Table 5). The following were the best combinations of two variables, (OD-chlor *a* 0.559, temp-OD 0.493, OD-MO 0.482) but these showed no better explanation power than the variable OD alone.

Figure 5 shows the resulting ordination diagram obtained by the CCA. Basically, the same groups were obtained as with the other techniques applied. The correlation of macrobenthic species to environmental data was approximately 0.51 for the first axis and 0.76 for the second one. The Monte-Carlo test showed a significant relation ($p< 0.001$) between the species and dissolved oxygen content in the bottom water, content of chlorophyll *a* in the sediment, organic matter and Eh of the surface sediment. Therefore, only the first two canonical axes were interpreted, representing 28.2 % of the variation between species and environmental data. In this model, only the environmental variables that presented significant relation ($p < 0.001$) were included in the forward selection procedure. In a general way the CCA analysis corroborated the trend shown by the other statistical techniques applied to the data, showing the same two groups of stations and the environmental variables that were best correlated with the biological data.

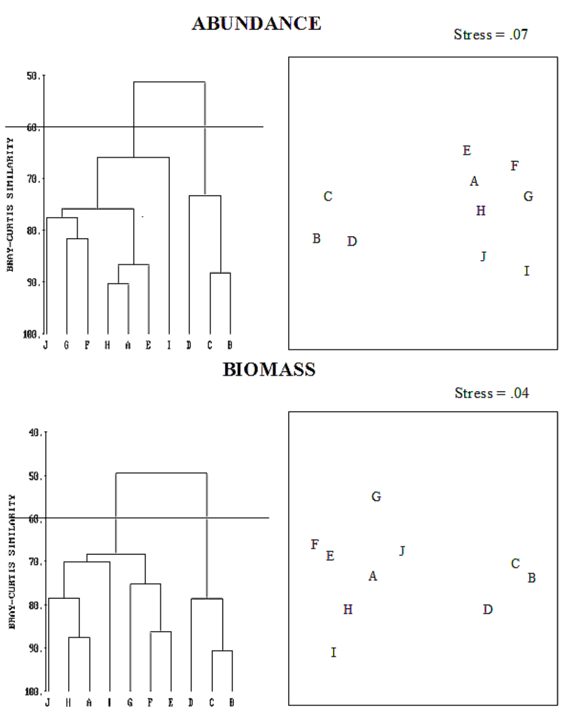

Figure 3. Dendrograms and n-MDS ordinations diagrams showing the results of grouping the sample stations (Q-mode). (a) by abundance. (b) by biomass. Sampling stations A to J.

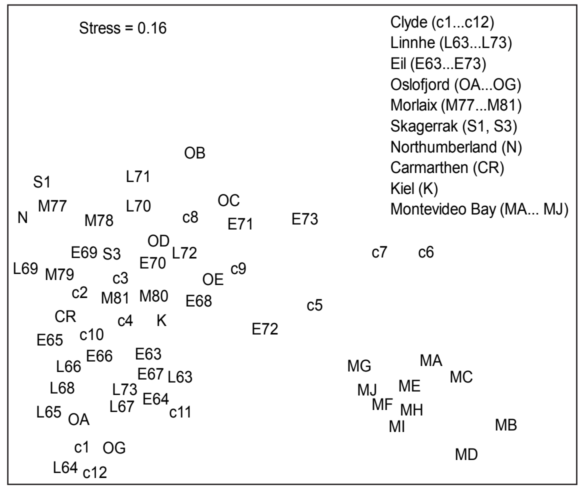

Figure 4. n-MDS ordination of phylum level "production" data from all the 50 sites of the NE Atlantic studied by Warwick and Clarke (1993) and the 10 samples from Montevideo Bay.

DISCUSSION AND CONCLUSIONS

Although Montevideo bay is a semi-enclosed protected environment it shows a great variability. As a component of the Río de la Plata estuary, it is affected by the mixture of oceanic with fresh water which produces great variations in environmental parameters such as salinity, temperature, dissolved oxygen concentration, turbidity and so on (Framiñan & Brown, 1996; Guerrero *et al.*, 1997). Natural variability, which can be a major source of stress to organisms, and a high nutrient concentration determine that estuaries are very productive but low diversity environments (Wilson, 1994). Low hydrodynamic energy in certain zones, deposition of organic matter on the sediment by natural eutrophication, in addition to anthropogenic inputs and industrial and dock activities, can produce in the fauna changes different from those expected due to natural variability of the system alone.

Shallow coastal habitats and estuaries are considered dynamic environments, characterised by great fluctuations in abiotic parameters and subject to continuous disturbance. These processes do not permit the normal development of communities towards stable stages, except as a mean condition on a large temporal-spatial scale (Turner *et al.*, 1995).

Individuals' density was very variable between the sampling stations and over the year of study, however it was not significantly correlated with the environmental parameters measured. This could simply be natural variability or it could be reflecting that in Montevideo bay other factors affect the structural patterns of the benthic communities, perhaps due to the anthropogenic activities. Species richness was very low throughout, and high abundances did not always correspond to a high species number, indicating that certain species are well adapted to the

Table 4. "Production" data of the 10 stations of Montevideo bay utilized in the meta - analysis. MA to MJ = sample stations. The nomenclature of the phyla are the same used by Warwick & Clarke (1993).

	Cnid	Plat	Neme	Nema	Pria	Sipu	Anne	Chel	Crus	Moll	Phor	Echi	Hemi	Chor
MA	0	0	0	1.1	0	0	2.7	0	0	96.1	0	0	0	0
MB	0	0	0	52.9	0	0	0	0	0	47.1	0	0	0	0
MC	0	0	0	48.7	0	0	0.3	0	0	51.0	0	0	0	0
MD	0	0	0	58.3	0	0	0	0	3.4	38.3	0	0	0	0
ME	0	0	0	2.6	0	0	10.8	0	0.7	83.9	0	0	0	0
MF	0	0	0	0.9	0	0	4.4	0	1.2	93.5	0	0	0	0
MG	0	0	0	3.0	0	0	12.9	0	14.2	70.0	0	0	0	0
MH	0	0	0	1.1	0	0	1.6	0	2.8	94.6	0	0	0	0
MI	0	0	0	0.5	0	0	11.5	0	2.9	85.2	0	0	0	0
MJ	0	0	0	1.3	0	0	13.9	0	2.8	82.0	0	0	0	0

environmental conditions prevailing in the bay. The general low diversity and high abundance of a single species were previously reported in other estuaries of similar characteristics, near to Montevideo bay (Olivier *et al.*, 1972; Ieno & Elias, 1995; Benvenuti, 1997; Ieno & Bastida, 1998), but high dominance of an annelid polychaete (*Heteromastus similis*) which in our study was not very abundant, has also been reported. According to Tenore (1972), the low diversity was a result of salinity conditions and the sediment instability in the Pamlico River estuary of North Carolina (USA). In Montevideo bay the range of salinity variation was also high but unlike other regions or estuaries this high variability is the common feature not an exceptional one. For that reason and because salinity did not showed any relationship with the faunistic patterns observed, the anthropogenic effects of the activities developed in the area could be the principal factor causing the very low diversity and species richness and high dominance of the small gastropod *H.* cf. *australis*, which is acting as an opportunistic, surface deposit-feeder, tolerating the high organic load in the sediment (Danulat *et al.*, 2002; Venturni *et al.*, 2004). Although *H.* cf. *australis* tolerates the high organic content of the sediments, this single variable was not correlated either with its density or its biomass as could be expected for this type of species. Thus, another important factor could be influencing its presence in the bay. The decline in number of *H.* cf. *australis* during some months of the study year also is reflecting that it is a short-lived species. The relation between the increase of organic matter, the reduction in the species number, in diversity and the enlargement of the single abundance of one or two species of small size have been well reported in previous studies (see for example Pearson & Rosenberg, 1978; Méndez *et al.*, 1998; Oug *et al.*, 1998; Sánchez-Mata *et al.*, 1999). These species are generally considered as indicators of organically enriched sediments. In such communities, perturbed by organic contamination, the frequency of disturbance is higher than the recovery rate, thus opportunistic species of small size and short lifetime will be favoured and could colonise such habitats with any type of biological competition. For this reason such species can be adapted to a high frequency of continuous disturbance. However, although *Heleobia* cf. *australis* was the most abundant (80% of the total abundance) and dominant macrobenthic species, many of the other species, especially the polychaetes *Nephtys fluviatilis, Alitta succinea, Heteromastus similis* and *Goniadides sp.*, have been reported from organic enriched environments elsewhere (e.g. Dauer & Conner, 1980; Amaral *et al.*, 1998; Arasaki *et al.*, 2004). The high frequency of occurrence of these species in addition to the presence of large-bodied nematodes species retained on a 0.4 mm sieve would be related to the high organic content of the sediments.

The lowest densities and species richness were always recorded in stations B, C and D (inner region of the bay). Besides the high organic content and chlor *a* content of these localities, reduced conditions in their surface sediments were recorded and their bottom water oxygen concentrations were very low (Table 1 and 2). Near these stations are the ANCAP refinery of hydrocarbons and the mouths of the Miguelete and Seco streams which constantly discharge immense amounts of wastes directly to water without any treatment García-Rodríguez *et al.*, 2010). There is no doubt that the effects of such discharges combined with the poor hydrodynamic conditions of this portion of the bay have a great influence over bottom communities.

On the other hand at stations. E, F, G, H and I species richness and faunal densities were higher than in the rest of the stations. St. E was at the mouth of the Pantanoso stream, where bottom currents are always high (personal observation of the authors)

Table 5. Environmental variables that showed highest Spearman's correlation coefficients with the abundance patterns of organisms.

Variable or combination of variables	Spearman's
O_2 (mg/l)	0.667
O_2 (mg/l) Chlor. *a* (mg/m^2)	0.559
O_2 (mg/l) T (0C)	0.493
O_2 (mg/l) % M. Org	0.482
O_2 (mg/l) Z (m)	0.45
O_2 (mg/l) % clay	0.441

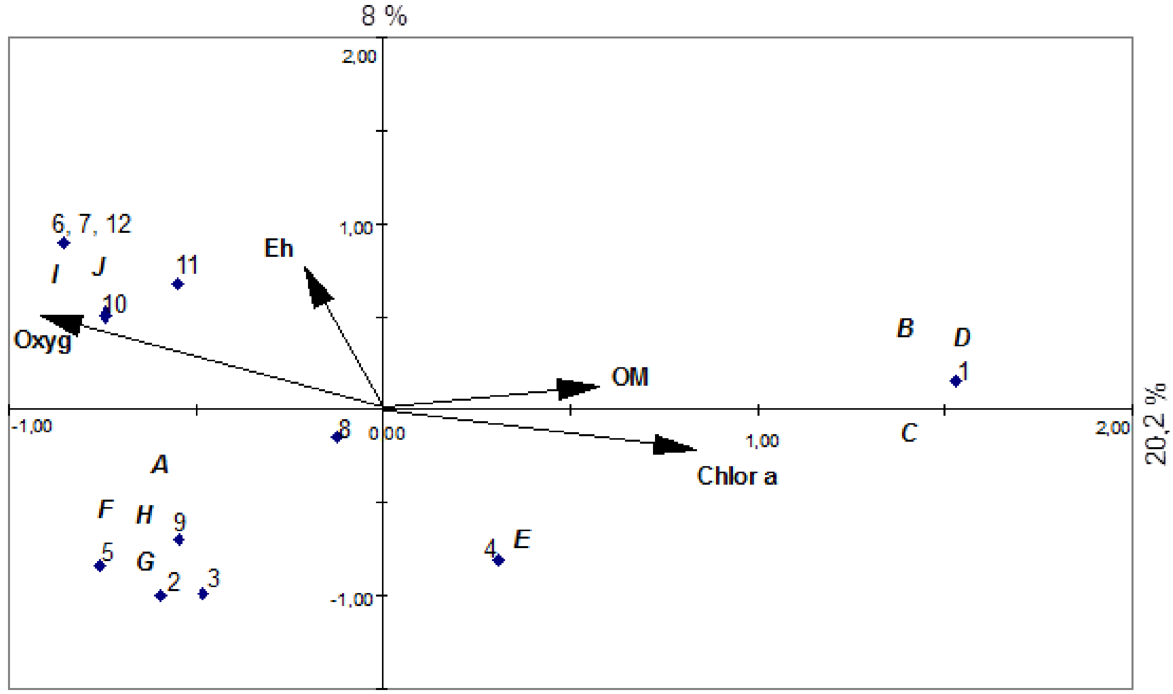

Figure 5. Ordination diagram obtained from the canonical correspondence analysis (CCA), showing the main groups formed, the percentage of the total variation of the first two axes are indicated. A to Z = sampling stations; 1 to 12 = macrobenthic species (see code in table 3); OM = organic matter content; Chlor a = chlorophyll *a* content; Eh = redox values; Oxyg = dissolved oxygen content of the bottom water.

and the sediment has a large percentage of sand. Possibly, because of these characteristics, the sediments were well oxygenated and so the macrobenthic species were under lesser stressful conditions than in the inner northeastern region of the bay. Because of the prevailing circulation patterns (Plata *et al.*, 1992; Moresco & Dol, 1996), which are clockwise, it is reasonable to suppose that currents could transport waste discharges of the Pantanoso stream and deposit these wastes in other inner portions of the bay where the hydrodynamic energy is low.

At stations F, G and I (outer southeast part of the bay) redox potential results showed that the sediment surface layer was aerobic, the bottom water was also well oxygenated and the organic matter content of the sediment was lower than in the inner part. Also this area had higher hydrodynamic exchange than the inner bay and according to Plata *et al.* (1992) the bay water is renewed through this entrance of the bay. These stations are probably better environments for the development of benthic organisms in the bay.

St J was one of the most variable in the sampling period in terms of density and species richness, probably because it is located in the access channel to the port. The frequent dredging of this channel is a continuous source of disturbance for the bottom fauna, constantly altering its structure.

On a temporal scale, the highest diversity, species richness and densities were recorded in autumn and winter 1997. Due to the increase in the hydrodynamic forces in these seasons the sediment column presented high levels of oxygenation and less organic content, making possible the better development of the benthic populations and the establishment of new species which were absent the rest of the year, such as *Goniadides* sp., *Sigambra grubii* and *Glycera* sp.

Although diversity, density and species richness were variable through out the sampling year the dominance of the very abundant specie**s**, *H.* cf. *australis*, was clear and constant over the period of study. According to Turner *et al.* (1995), this fact could be reflecting community stability even when exposed to an important and significant disturbance, such as the constant increase of organic matter in an ecosystem.

In shallow environments, changes in abundance and diversity can also be produced by climate factors. Storms produce the movement of bottom sediments, erosion and deposition, which are very important causes of infauna mortality (Posey *et al.*, 1996). In Montevideo Bay this could be determining the variability observed in the subtidal community, however, storms in this area are not very severe, rather, they are more likely to be disturbances representing a positive factor contributing to the health and cleaning of the ecosystem. It is relevant to emphasise that, a large number of replicates were used in this study, in attempt to overcome criticisms of this type of temporal analysis, that comparisons among the same station over time may be distorted by small-scale spatial variations, because the samples will not necessarily come from the same type of patch at each time of sampling (Morrisey *et al.*, 1992 a; b).

Although the bay was a very variable system it was possible to differentiate, by means of the cluster analyses and n-MDS ordination, discrete faunal associations, in regions with particular environmental characteristics. The cluster formed by stations B, C and D that showed less abundance and biomass of benthic organisms, corresponds to the inner part of the bay where environmental conditions are very unfavourable. Water circulation is limited; there is a high percentage of organic matter in sediments and a tendency to the presence of reduced sediments. The other cluster formed by the remaining stations A, E, F, G, H, I and J corresponds to regions of the bay which are heterogeneous but in general have more favourable environmental characteristics than in the inner region. At stations F and G particularly, the high water circulation and oxygenation of the sediment column and the smaller percentage of organic matter may be responsible for the great abundance and biomass of benthic organisms found. The advantage of ordination methods over cluster analysis is that the former shows the inter-relationships that exist between samples on a continuous scale while the latter tries to group samples in discrete clusters and is most appropriate to define groups of stations with a distinguishable community structure, in cases with strong pollution gradients. In this case the ordination method showed the same two groups obtained by the cluster analysis, which clearly confirms that the benthic community studied has, in other parts of the bay, a structure different from that in the most polluted inner part. This trend was also verified by the CCA analysis, in which basically the same two groups of stations were obtained. The four environmental variables identified in this analysis explained almost 28.2% of the variance in species data. Such a figure does not imply that the ordination was a poor representation (ter Braak, 1990). "Noise" in species data sets typically accounts for 10-50% of the total information (Gauch, 1982). As both the BIO-ENV procedure and CCA identified basically the same environmental variables influencing the benthic distributions, the results can be viewed with a reasonable degree of confidence. One should not forget, as was pointed out by Etter & Grassle (1992) and Clarke & Ainsworth (1993), that there can be no guarantee that highly correlated environmental variables are causative. Moreover, we can see clearly that large-bodied nematodes were preferentially found in the group formed by the inner stations, in which the organic matter and chlorophyll *a* content was high, and also presented the highest bottom temperatures. On the other hand, we can distinguish two subgroups within the second group formed in the cluster and MDS diagrams. One consists of stations I and J, characterised by the polychaetes *Glycera sp.* and *S. grubii*, and also by ostracods, isopods and balanus. In the other subgroup, that included stations. A, H, G, F and also E, *N. fluviatylis, A. succinea, Goniadides sp., Erodona mactroides* and *H. similis* were more abundant. The gastropod *H.* cf. *australis* showed more preference for the second group of stations but it was nearly in the centre of the CCA diagram.

When compared to the training data set (Warwick & Clarke, 1993), all stations of Montevideo Bay appeared in the right extreme of the diagram, near stations C6 and C7 of Clyde sewage-sludge dump-ground. According to the authors, these two sites are situated close to the dump centre and showed signs of gross pollution. Most of the stations of Montevideo Bay are situated in the diagram at the same position of the stations mentioned above (C6 and C7), and two of them (B and D) are situated more to the right. This suggests that the bay could be a more severe and polluted environment than the most extreme sites used for making the training data set. The fact that the n-MDS configuration was not identical to the original in Warwick and Clarke (1993) could be reflecting that Montevideo Bay is also under the effects of other contaminants different from organic ones.

In summary, the benthic fauna of Montevideo Bay has patterns of very low diversity and high dominance of a single species when compared to those estuaries of equal characteristics at similar latitudes. Although the only environmental variable measured that relate to anthrophogenic activities was organic matter content in bottom sediment, this and other factors appeared to be related to the distribution patterns of the benthic fauna and contributed to this general trend of low diversity and high dominance of the gastropod *H.* cf. *australis*. Spatially the Bay can be clearly divided in two regions with different faunal and environmental characteristics. These two regions are reflecting the difference in the degree of stress under what the Bay is subjected. Findings obtained in this investigation can be a basis for future studies in the region and emphasise the urgent necessity to establish an environmental monitoring system in the area. Since the concentration of dissolved oxygen was one of the critical variables detected in the present study and the organic load is very high, one of the first things that could be taken into account is to attempt to diminish the organic waste discharged into the bay, to allow a rise in oxygen concentration in the sediments, which would promote the settlement of more macrofauna. Finally, the Phylum level meta-analysis seems to be a good tool for assesses the pollution status of a coastal area, especially because it represents an important cost reduction in this type of research programs.

ACKNOWLEDGEMENTS

This study was part of an integrated research project of the Sección Oceanología of Facultad de Ciencias supported by IMM (Intendencia Municipal de Montevideo) and CSIC (Comisión Sectorial de Investigación Científica). Authors thank ANII-SNI (National Agency) and the Dive Grou (GRUBU) of the Uruguayan Army for their support in the field sampling. Especial thanks are also due to M. Gómez, M. Rodríguez, G. Lacerot, A. Martínez, A. Carranza, B. Yanicelli and K. Sanz of the Facultad de Ciencias for their invaluable help in the field sampling and laboratory work. We wish to further acknowledge the help of Dr. Bob Clarke, who commented and made useful suggestions about this paper. Special thank to D. Siqueiros for his kind invitation to contribute to this volume of Oceánides.

REFERENCES

Amaral, A.C.Z., E.H. Morgado & L.B. Salvador. 1998. Poliquetas Bioindicadores de Poluição Orgânica em Praias Paulistas. *Revista Brasileira de Biologia*, 58: 307-316.

Arasaki, E., P. Muniz & A.M.S. Pires-Vanin .2004. A functional analysis o the enthic macrofauna of the São Sebastião Channel (southeastern Brazil). *Marine Ecology*, 25: 249 -263

Benvenuti, C.E., 1997. Benthic invertebrates, 43-46. In: *Subtropical convergence marine ecosystem. The coast and the sea in the warm temperate southwestern atlantic,* (ed.) U. Seeliger, C. Odebrecht and J.P. Castello, New York: Springer Verlag, Heidelberg.

Bray, J.R. & J.T. Curtis. 1957. An ordination of the upland forest communities in southern Wisconsin. *Ecological Monographs*, 27,:325-349.

Byers, S.C., E.L. Mills & P.L. Stewart. 1978. A comparison of methods to determining organic carbon in marine sediments, with suggestion for a standard method. *Hydrobiologia*, 58, 43-57.

Clarke, K.R. & M. Ainsworth: 1993. A method of linking multivariate community structure to environmental variables. *Marine Ecology Progress Series*, 92: 205-219.

Danulat, E., P. Muniz, J. García-Alonso & B. Yannicelli. 2002. First assessment of the highly contaminated harbour of Montevideo, Uruguay. *Marine Pollution Bulletin*, 44: 554 -565.

Dauer, D.M., 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. Marine Pollution Bulletin, 26: 249-257.

Dauer, D.M. & W.G. Conner. 1980. Effects of moderate sewage input on benthic polychaete populations. *Estuarine and Marine Sciences*, 10: 335-346.

Demicheli, M.A., 1984. Estudios exploratorios del infralitoral de las playas arenosas uruguayas. I. Playa Portezuelo. *Comunicaciones de la Sociedad Malacológica del Uruguay*, 6 (47): 235-249.

Demicheli, M.A., 1986. Estudios exploratorios del infralitoral de las playas arenosas uruguayas. II. Datos complementarios sobre Playa Portezuelo. *Comunicaciones de la Sociedad Malacológica del Uruguay*, 6(48): 287-290.

Etter, R.J. & J.F. Grassle. 1992. Patterns of species diversity in the deep sea as a function of sediment particle size diversity. *Nature*, 360: 609-610.

Folk, R.L. & W. C. Ward. 1957. Brazos River bar: a study of the significance of grain size parameters. *Journal of sedimentary Petrology*, 27: 3-26.

Framiñan, M.B. & O. B. Brown. 1996. Study of the Río de la Plata turbidity front, Part I: spatial and temporal distribution. *Continental Shelf Research*, 16: 1259-1282.

García-Rodríguez, F., M. Hutton, E. Brugnoli, N. Venturini, L. Del Puerto, H. Inda, R. Bracco, L. Burone & P. Muniz. 2010. Assessing the effect of natural variability and human impacts on the environmental quality of a coastal metropolitan area (Montevideo, Bay, Uruguay). *Pan-American Journal of Aquatic Sciences*, 5: 90-99.

Gauch, H.G. 1982. *Multivariate analysis in community ecology* Cambridge: Cambridge University Press.

Grasshoff, K. 1983. Determination of oxygen. In *Methods of seawater analysis*, (.ed.) K. Grasshoff, M. Ehrjardt & K.V. Kremling Weinheim. Verlag Chemie.

Gray, J.S., 1979. Pollution-induced changes in populations. *Phil Trans R Soc Lond B,* 286:545-561.

Guerrero, R.A., E.M. Acha, M. B. Framiñan & C.A. Lasta. 1997. Physical oceanography of the Río de la Plata estuary, Argentina. *Continental Shelf Research*, 17:727-742.

Heip, C. 1992. Benthic studies: summary and conclusions. *Marine Ecology Progress Series*, 91: 265-269.

Ieno, E.N. & R. O. Bastida. 1998. Spatial and temporal patterns in coastal macrobenthos of Samborombon Bay, Argentina: a case of study of very low diversity. *Estuaries*, 21(4B): 690-699.

Ieno, E.N. & E. Elias. 1995. Studies on a southern polychaete Capitellidae *Heteromastus similis* Southern, 1921 in Mar Chiquita brackish coastal lagoon, Argentina. *Nerítica*, 9:23-32.

Kruskal, J.B. & M. Wish. 1978. *Multidimensional Scaling*. Beverly Hills: California Sage Publications.

López-Jamar, E., 1985. Distribución espacial del poliqueto *Spiochaetopterus costarum* en las Rías Bajas de Galicia y su posible utilización como indicador de contaminación orgánica en el sedimento. *Boletín del Instituto Español de Oceanografía*, 2: 68-76.

Lorenzen, C.J., 1967. Determination of chlorophill and pheopigments: Spectrophotometric equations. *Limnology and Oceanography*, 12: 343-346.

Méndez, N., J. Flos & J. Romero. 1998. Littoral soft-bottom polychaete communities in a pollution gradient in front of barcelona (western Mediterranean, Spain). *Bulletin of marine Science*, 63:167-178.

Moresco, H. & I. Dol. 1996. Metales en sedimentos de la Bahía de Montevideo. *Revista Asociación Ciencias Naturales del Litoral*, 27:1-5.

Morrisey, D.J., A.J. Underwood, L. Howitt & J.S. Stark. 1992a. Temporal variation in soft-sediment benthos. *Journal Experimental Marine Biology and Ecology*, 164:233-245.

Morrisey, D.J., L. Howitt, A.J. Underwood & J.S. Stark. 1992b. Spatial variation in soft-sediment benthos. *Marine Ecology Progress Series*, 81: 197-204.

Muniz, P., N. Venturini & A. Martínez. 2002. Physico-chemical characteristics and pollutants of the benthic environment in the Montevideo coastal zone, Uruguay. *Marine Pollution Bulletin*, 44: 962-968.

Muniz, P., E. Danulat, B. Yannicelli, J. García-Alonso, G. Medina & M. Bícego. 2004. Assessment of contamination by heavy metals and petroleum hydrocarbons in sediments of Montevideo harbour (Uruguay). *Environment International*, 29:1019-1028.

Muniz, P & N. Venturini. 2011. *Environmental conditions in the coast of Montevideo, Uruguay: historical aspects, present status and perspectives of habitat degradation and uses*. Encyclopedia of Environmental health. v.: 5 , 1, p.: 590 – 601. Jerome Nriagu (Ed.) Editorial: Elsevier B.V, Amsterdan.

Muniz, P., N. Venturini, M. Hutton, N. Kandratavicius, A. Pita, E. Brugnoli, L. Burone & F. García-Rodríguez. 2011. Ecosystem health of Montevideo coastal zone: a multi approach using some different benthic indicators to improve a ten-year-ago assessment. *Journal of Sea Research*, 65: 38-50.

Muniz, P., P. Lana, N. Venturini, R. Elías, E. Vallarino, C. Bremec, C. Martins, L. Sandrini Neto. 2013. *Un manual de protocolos para evaluar la contaminación marina por efluentes domésticos.* Vol. 1, 129pp. Editorial: UdelaR, Montevideo.

Nielsen, E.M. & C.C.E. Hopkins. 1992. Regional variability in fish-prawn communities and catches in the Barents Sea, and their relationship to the environment. *ICES marine Science Symposium*, 195: 331-348.

Olivier, S.R., A. Escofet, P. Penchaszadeh & J. M. Orensanz. 1972. Estudios ecológicos en la región estuarial de Mar Chiquita (Buenos Aires, Argentina). I: Las comunidades bentónicas. *Anales Sociedad Científica Argentina*, 193:237-261.

Oug, E., N. Kristoffer & R. Brage. 1998. Relationship between soft bottom macrofauna and polycyclic aromatic hydrocarbons (PAH) from smelter discharge in Norwegian fjords and coastal waters. *Marine Ecology Progress Series*, 173:39-52.

Pearson, T.H. & R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Review*, 16: 229-331.

Pielou, E.C., 1975. *Ecological diversity*. New York: John Wiley.

Pires, A.M.S., 1992. Structure abd dynamics of benthic megafauna on the continental shelf offshore of Ubatuba, southeastern Brazil. *Mainer Ecology Progress Series*, 86:63-76.

Plata, A., A. Kurucz, C. Vera, R. Suárez, C. Ures & J. Pintos. 1992. Circulación y renovación del agua en la Bahía de Montevideo. *Informe de avance. Proyecto URU/8/007*. Vienna: Organismo Internacional de Energía Atómica (OIEA).

Posey, M., W. Lindberg, T. Alphin & F. Vose. 1996. Influence of storm disturbance on an offshore benthic community. *Bulletin of marine Science*, 59:523-529.

Ritter, C. & P. A. Montagna. 1999. Seasonal hypoxia and models of benthic response in a Texas Bay. *Estuaries*, 22:7-20.

Romesburg, H.C. 1984. *Cluster analysis for researchers*. California: Wadsworth Inc.

Rosenberg, R., 1985. Eutrophication, the future marine coastal nuisance? *Marine Pollution Bulletin*, 16:227-231.

Sánchez-Mata, A., M. Glémarec & J. Mora. 1999. Physico-chemical structure of the benthic environment of a Galician ría (Ría de Ares-Betanzos, north-west Spain). *Journal of the Marine Biological Association of the United Kingdom*, 79:1-21.

Scarabino, V., S. Maytía & M. Caches. 1975. Carta binómica litoral del departamento de Montevideo. I. Niveles superiores del sistema litoral. *Comunicaciones de la Sociedad Malacológica del Uruguay,* 4(29):117-129.

Seys, J.J., P.M. Meire, J. Coosen & J. A. Graeymeersch. 1994. Long-term changes (1979-89) in the intertidal macrozoobenthos of the Oosterschelde estuary: Are patterns in total density, biomass and diversity induced by the construction of the storm-surge barrier? *Hydrobiologia*, 282/283: 251-264.

Shannon, C.E. & Weaver, W.W., 1963. The mathematical theory of communication. University of Illinois Press, Urbana.

Suguio, K., 1973. *Introdução à sedimentologia*. São Paulo: Edgard Blucher.

ter Braak, C.J.F., 1986. Weighted averaging, logistic regression and the Gaussian response model. *Vegetatio*, 65: 3-11.

ter Braak, C.J.F., 1988. Canoco: a fortram program for canonical community ordination by partial, detrended, canonical, correspondence analysis, principal components analysis and redundancy analysis. Version 2.1. *Technical Report: LWA-88-02*, 95p. Agricultural Mathematics Group, Wageningen, The Netherlands.

ter Braak, C.J.F., 1990. *Updates notes: Canoco version 3.10*. Wageningen: Copyright Agricultural Mathematics Group.

Tenore, K.R., 1972. Macrobenthos of the Pamlico River Estuary, North Carolina. *Ecological Monographs*, 42: 51-69.

Turner, S.J., S.F. Thrush, R.D. Pridmore, J.E. Hewitt, V.J. Cummings & M. Maskery. 1995. Are soft-sediment communities stable? An example from a windy harbour. *Marine Ecology Progress Series*, 120: 219-230.

Venturini, N., P. Muniz & M. Rodríguez. 2004. Macrobenthic subtidal communities in relation to sediment pollution: the phylum-level meta-analysis approach in a south-eastern coatal region of South America. *Marine Biology*, 144: 119-126.

Venturini, N., A. Pita, E. Brugnoli, F. García-Rodríguez, L. Burone, N. Kandratavicius, M. Hutton & P. Muniz. 2012. Benthic trophic status of sediments in a metropolitan area (Rio de la Plata estuary): linkages with natural and human pressures. *Estuarine Coastal and Shelf Science*, 112: 139-152.

Venturini, N., M. Bícego, S. Taniguchi, S. Sasaki, F. García-rodríguez, E. Brugnoli & P. Muniz. 2015. A multi-molecular marker assessment of organic pollution in shore sediments from the Río de la Plata Estuary, SW Atlantic. *Marine Pollution Bulletin*, 91: 461-475.

Warwick, R.M., 1988. Effects on community structure of a pollutant gradient - summary. *Marine Ecology Progress Series*, 46: 207-211.

Warwick, R.M. & K.R. Clarke, 1993. Comparing the severity of disturbance: a meta - analysis of marine macrobenthic community data. . *Marine Ecology Progress Series,* 92: 221-231.

Wilson, J.G., 1994. The role of bioindicators in estuarine management. *Estuaries*, 17(1A): 94-101.

Zobell, C.E., 1946. Studies on redox potential of marine sediments. *Bulletin of the American Association of Petrology and Geology*, 30: 477-513.