Bolm Inst. oceanogr., S Paulo, 34(único):13-21, 1986

A MULTIVARIATE APPROACH TO ENVIRONMENTAL-ZOOPLANKTON RELATIONSHIPS IN MALDONADO BAY (URUGUAY)

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Synopsis

Environment-zooplankton relationships were analysed in Maldonado Bay (Uruguay), an estuarine area between the River Plate and the Atlantic Ocean. This was done through Principal Component Analysis. Most of the environment variability is accounted for, primarily, by the outflow of the River Plate and the inflow of coastal waters which change through the annual cycle, and in the second place by surface water conditions. On the other hand, most of the zooplankton variability is accounted for by 17 taxa abundant in April and February and by one dominant species present only from May to August. A second source of zooplanktonic variability is due to species which occurred in fall only The main observed variability occurred on an annual scale. On it, variations on smaller scales overlap: from one day to another, between Maldonado Bay and the adjacent waters of the River Plate. The main factors involved were different at each scale. The Bay is relatively isolated from adjacent waters, but the degree of isolation varies throughout the year. The influence of coastal water is greater and occurs first outside the Bay. Biological processes may develop under different conditions in the Bay and in the adjacent waters of the River Plate.

Descriptors: Principal component analysis, Seasonal variation, Zooplankton, Ecology, Coastal zone, Environmental conditions, Estuaries, Maldonado Bay: Uruguay.
Descritores: Análise de componentes principais, Variação sazonal, Zooplâncton, Ecologia, Zona costeira, Condições ambientais, Estuários, Baía de Maldonado: Uruguai.

Introduction

In tourist areas, special attention should be devoted to the conservation of the landscape, to environmental conditions, and consequently to their ecology.

In Uruguay, the biggest tourist complex is Punta del Este, on Maldonado Bay. This Bay has a variable environment under the influence of the River Plate - which is an estuary, in spite of its name - and the coastal waters of the Atlantic Ocean. Its behavior is virtualy unknown. So, as a first step to an understanding of its ecology, a one-year sampling program of zooplankton and environmental data was set up. The goals were not only to record information in a systematic way, but also to study variability and relationships among variables, which in turn should be useful for an understanding of highly variable aquatic environments in general, besides Maldonado Bay. Other topics covered by this sampling program were analysed by Abdala (1981), Ayup (1981), Baliño (1981), Pereyra (1981) and Urruti (1981).

The large amount of data recorded were analysed by means of Principal Components, in order to obtain a comprehensive image of the system. Preliminary results in the first two components were reported to the II International Conference on Ecology and Environmental Quality (Milstein, 1983).

Publ. n. 650 do Inst. oceanogr. da Usp.

Area studied

Maldonado Bay is on the border line between the River Plate and the Atlantic Ocean (Fig. 1). It is a protected area of about 6 km^2 and 10-11 m deep. The Gorriti Island separates the Bay from the River Plate, which is an exposed and deeper region. Tides are negligible, only of 35 cm amplitude (Balay, 1961). During the investigation period water temperature fluctuated between 11.5°C in winter and 24°C in summer, and no thermoclines were recorded; salinity fluctuated between 13°/oo and 35°/oo, with haloclines in fall (April, May) and winter (July, August), and in November.

Studies on meteorology, hydrology and geology of the area were done by Perez Fontana & de Castro (1942), Balay (1961), SOHMA (1977), Proyecto de Conservación y Mejora de Playas (1979), Urien *et al.* (1980), François *et al.* (1981), Ayup (1981) and Urruti (1981).

The sewage of Punta del Este pours out at two points near Maldonado Bay: Punta de la Salina and Punta del Chileno. At the latter point there is a sewage primary-treatment plant. Some microbiological topics related to these sewage outflows during one summer period were studied by Cristar & Schlcolnik (1980). These authors found that the sandy beach near Punta del Chileno is not affected by those outflows, and the Atlantic rocky coast of Punta del Este near La Salina is only slightly affected. This rocky coast is not a bathing area.

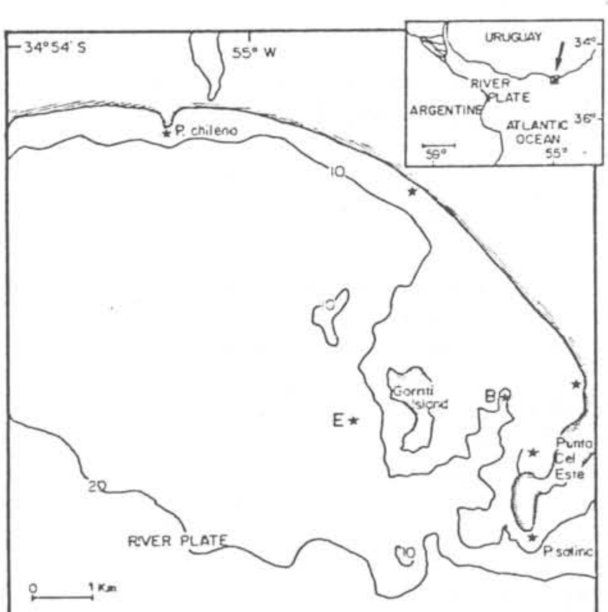

Fig. 1. Area studied. Small map: arrow points out to Maldonado Bay; scale represents 100 km. Large map: location of stations (stars); B = Bay station; E = Exterior station; 10 m and 20 m isobathes drawn.

Most of the biological research done in Maldonado Bay is on benthonic organisms: de Buen (1950), Amaro (1967), Maytía & Scarabino (1979) and Neirotti (1980). Exceptions are an old descriptive paper on phytoplankton (Barattini & Martinez Montero, 1932) and the above mentioned studies by Baliño (1981) and Pereyra (1981) in the framework of the present sampling program.

Material and methods

The sampling strategy employed enabled the detection of changes inside and outside the Bay at day-scale and month-scale during the year. This strategy was discussed in a previous paper (Milstein, 1984). Samples were taken between April 1980 and February 1981. Each season was sampled during two consecutive months, each month during two consecutive days (except in April and November, due to bad weather), and each day samples were taken in the afternoon. Samples were collected at two stations (Fig. 1), one in the middle of the Bay (B) and the other on the other side of Gorriti Island (E), in order to compare the behavior of variables in the Bay and in the adjacente waters of the River Plate.

The following parameters were measured at each station: transparency (Secchi disk); oxygen and chlorophyll-*a* at several depths in the euphotic layer; temperature and salinity profiles with a thermosalinometer; nutrients (nitrate, nitrite, phosphate, silicate) at surface and bottom. Waters for nutrients were collected once each month. Zooplankton were caught through oblique tows (speed and time standardized) with a Bongo net of 20 cm diameter; both nets were of 180 µm mesh, and one net was equipped with a flowmeter.

Besides these two stations, five coastal stations were sampled for environmental parameters (Fig. 1). These data are not analysed in the present study, and were studied by Ayup (1981) and Urruti (1981).

Dissolved oxygen was determined by the Winkler method. Chlorophyll-*a* was determined by the trichromatic method (Vollenweider, 1974). Dissolved oxygen and chlorophyll-*a* were integrated through the euphotic layer. The total pigments/chlorophyll-*a* quotient (DD) was also computed (Margalef, 1960). Nutrients were analyzed by Ayup (1981), who used spectrophotometric techniques.

Holoplankton were identified at the species level, but meroplankton were grouped into broad taxonomic categories (Table 2); their numbers were expressed as individuals per cubic meter and then transformed to Log(x+1).

Data were processed by means of the STRUCT program (Ibanez, 1973*a*). This program makes a Principal Component Analysis (PCA) of the correlation matrix of two sets of data (environmental data and zooplankton counts) and also calculates the correlations between the components of the two sets. The environmental data matrix was of 28 observations X 14 variables, and the zooplankton one of 56 observations X 34 variables. Since two zooplankton samples were taken simultaneously each time (Bongo net), to both samples of each pair correspond one and the same set of environmental data. Thus, for the calculation of correlations between the components of both data sets, each environmental observation was doubled.

Significance tests of the components are available for multinormal distribution of the variables, which seldom occur in ecology. Thus, empirical criteria are used for accepting a component and for the inclusion of variables in a component. In the environmental analysis the criteria of Ibanez & Dallot (1969) and Flos (1979) was follow: components derived from eigenvalues greater than 1 were retained. In the zooplankton analysis, a random distributed variable was included in the data set, and all components previous to the one which selects this variable are retained (Ibanez, 1973*b*). Following Ibanez & Seguin (1972), each principal component was defined by the variables with loadings greater than 0.50. Other details of the PCA method as applied to biology are found in Seal (1964), Lefebvre (1976) and Jeffers (1978).

Results

Seventy-two percent of the environmental variability was accounted for by four environmental components (EC), and 59% of the zooplanktonic variability by three zooplanktonic components (ZC). Remaining components of both analyses accounted for less than 9% of the overall variability, and were neglected.

Temperature, salinity, silicate and phosphate are the parameters which have greater weight in the first EC (EC1) (Table 1). Thus, this component corresponds to opposition between saline coastal water rich in phosphate, and less saline estuarine water rich in silicate. It also shows changes of both water masses through the annual temperature cycle: its higher positive values occurred in summer when coastal waters were present in all the water column (homogeneous high salinity and high temperature); its highest negative values occurred in August, when estuarine water was present in all the water column (homogeneous low salinity); values between 0 and -1 correspond to stratified waters (April, May, July and November, Fig. 2a). This component also shows differences between consecutive days and between stations.

Table 1. Environmental components: percentage of variability accounted for each component, and parameters with saturations over 0.50

	EC1	EC2	EC3	EC4
Variability (%)	29	20	14	9
Transparency	-	0.86	-	-
Temperature (surface)	0.62	0.61	-0.63	-
Temperature (bottom)	0.50	0.71	-	-
Salinity (surface)	0.74	-	-	-
Salinity (bottom)	0.82	-	-	-
Oxygen (euphotic layer)	-	0.72	-	-
Chlorophyll (euph. layer)	-	-	-	0.72
DD	-	-	0.56	-
Phosphate (surface)	0.52	-	-	-
Phosphate (bottom)	0.74	-	-	-
Silicate (surface)	-0.54	-	0.76	-
Silicate (bottom)	-0.74	-	-	-
Nitrite (surface)	-	0.63	-	-
Nitrite (bottom)	-	-	0.68	-

The EC2 reflects conditions in surface waters (Table 1). This component follows and annual cycle with its highest values occurring when temperature and dissolved oxygen were high. It also shows differences on a small scale, mainly in May (Fig. 2b), where it points out to a sharp change between consecutive days, more pronounced at the Exterior station.

The EC3 is difficult to explain. It is composed by three variables related to surface waters (total pigments/ chlorophyll-*a* quotient (DD), surface silicate and surface temperature) and one to bottom waters (nitrite) (Table 1). Its highest values occurred in July, when surface water was cold and peaks of the other three variables were registered. It also shows strong differences between stations during the fall sampling days and points out to a phytoplanktonic bloom recorded on the first sampling day of January at the Exterior station (Fig. 2c).

The EC4 is a phytoplanktonic component (Table 1) which reflects mainly the bloom of January (Fig. 2d). On that occasion, 69 mg chlorophyll-a/m^3 was recorded in the surface waters at the Exterior station, while 4.9 mg/m^3 occurred in the Bay. The bloom disappeared 24 hours later, when the amount of chlorophyll-*a* at the Exterior station surface waters decreased to 8 mg/m^3. In addition to this phenomenon, this component also points out to strong differences between stations in May.

The first zooplanktonic component (ZC1) is a general quantitative factor. It is a bipolar component which brings together 17 coastal water taxa which were abundant in April and February, as opposed to the estuarine cladoceran *Pleopis* (= *Podon*) *polyphemoides*, which was present only in May-July-August, and in large numbers (Table 2). This component follows an annual cycle, with clearly different values in each month. It also shows strong differences between consecutive days and between synoptic stations in July, August and February

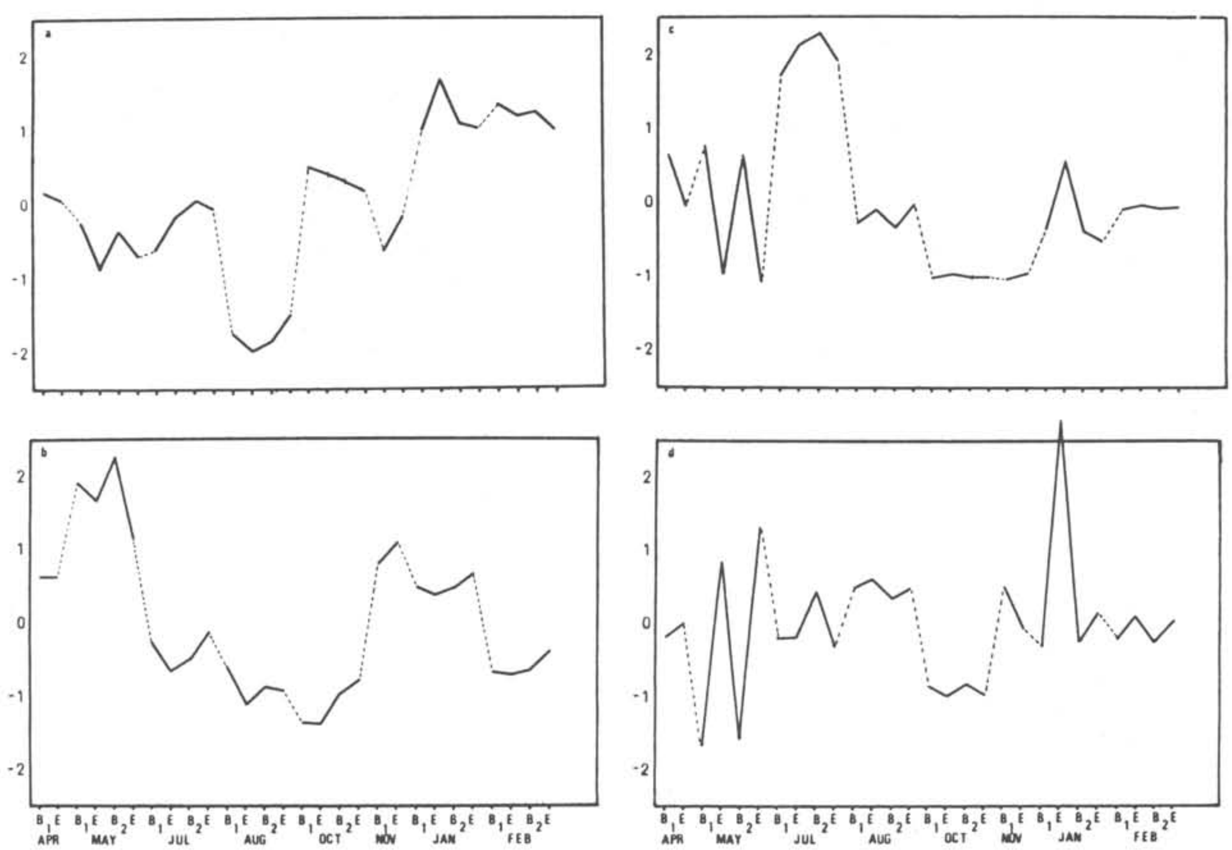

Fig. 2. Environmental components. a) EC1. b) EC2. c) EC3. d) EC4. Continuous lines join samples taken the same month; B = Bay station; E = Exterior station; 1 and 2 correspond to the first and second sampling day of each month.

Table 2. Zooplanktonic components: percentage of variability accounted for each component, and taxa with saturations over 0.50

	ZC1	ZC2	ZC3
Variability (%)	32	17	10
Cyphonaut larvae	0.67	-	-
Decapod larvae	0.67	-	-
Cirriped cypris	0.87	-	-
Bivalve larvae	0.83	-	-
Gastropod larvae	0.93	-	-
Polychaete larvae	0.89	-	-
Fish eggs	0.69	-	-
Fish larvae	0.74	-	-
Oikopleura sp	0.81	-	-
Sagitta spp	0.91	-	-
Coelenterates	0.81	-	-
Mysids	0.50	-	-
Paracalanus crassirostris	0.81	-	-
Hemicyclops thalassius	0.73	-	-
Euterpina acutifrons	0.72	-	-
Acartia tonsa	0.58	-	0.56
Corycaeus amazonicus	0.68	0.55	-
Corycaeus dubius	-	0.95	-
Eucalanus pileatus	-	0.82	-
E. pileatus nauplii	-	0.91	-
Centropages velificatus	-	0.78	-
Oncaea curta	-	0.72	-
Noctiluca sp	-	0.65	-
Rotifers	-	0.68	-
Pleopis polyphemoides	-0.51	-	-
Oithona nana	-	-	0.51
Labidocera fluviatilis	-	-	0.73
L. fluviatilis nauplii	-	-	0.86
Paracalanus quassimodo	-	-	-
Ctenocalanus vanus	-	-	-
Oithona similis	-	-	-
Evadne nordmani	-	-	-
Cirriped nauplii	-	-	-
Echinoderm larvae	-	-	-

(Fig. 3a). It is correlated to the EC1 (r = 0.68).

The ZC2 is a fall component which groups eight species (Table 2). It points out to strong differences between synoptic stations in April and on the second day of May, and between consecutive days at the Exterior station in May (Fig. 3b). Its distribution is correlated to the EC2 (r = 0.65).

The ZC3 brings together three copepod species of very different size, which were present all the year round: the large *Labidocera fluviatilis*, the medium-size *Acartia tonsa*, and the small *Oithona nana* (Table 2). The component points out to the most relevant small-scale phenomena, which occurred in May, July, August and January (Fig. 3c).

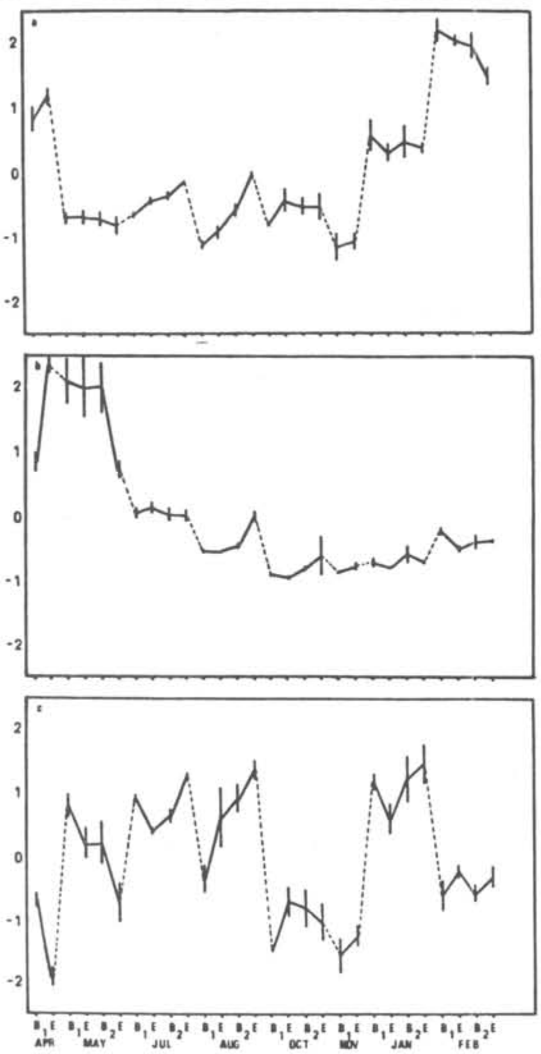

Fig. 3. Zooplanktonic components. a) ZC1. b) ZC2. c) ZC3. Vertical lines join values of two simultaneous samples; continuous lines join samples taken the same month; B = Bay station; E = Exterior station; 1 and 2 correspond to the first and second sampling day of each month.

Discussion

The first two components of both environment and zooplankton show that the main observed variability occurred on the annual scale. However, this general pattern is overlapped by variations on a smaller scale, especially in zooplankton. These small-scale variations became more evident in the third and fourth components.

On an annual scale, temperature is the isolated variable that shows more clearly a cycle. It has a large contribution to the first three EC. The other parameters do not show a clear cycle, but their combination into components does.

In relation to salinity, two situations can be noticed: stratification or low salinity homogeneous waters in fall-winter (estuarine circulation) and homogeneous saline water in spring-summer (marine circulation). These situations depend on the outflow on the River Plate and the inflow of coastal waters. The stratified waters recorded in November are an exception to this pattern. The dominance of low salinity surface waters in fall-winter and the opposite situation in spring-summer were recorded previously in the area (SOHMA, 1977): the average surface monthly salinities at Punta del Este Port during the period 1970-1975 were lower than 25°/oo between April and August, and higher in the other months. In the present study, the EC1 points out to this trend.

Silicate and phosphate concentrations, the other important variables of the EC1, were more highly correlated with salinity than with temperature. François *et al.* (1981), working with monthly samples from 12 stations at the Uruguayan coast of the River Plate and Atlantic Ocean, also found a negative correlation between salinity and silicate, but not with phosphate. These authors stress that silicate concentration seems to depend on the River Plate dynamics, while that of phosphate would be a function of local inflows at each sampling station. Taking into account not only the Bay and Exterior stations of our study, but also the mentioned coastal stations sampled on the same days, the impact of human activities becomes clear: phosphate concentrations were higher near the sewage outflows, especially in summer. Up to 2.3 µg at-P/l was recorded at all stations except near the sewage outflows of El Chileno and La Salina, where concentrations reached up to 6.8 µg at/l and 16.6 µg at/l, respectively, during the summer tourist period (Urruti, 1981). At the Bay and Exterior stations this influence was not so evident, thus showing that the dilution and degradation processes are still sufficient to absorb the present level inflows.

Another source of variability existed in the upper layers of the sea. Fluctuations in light and oxygen (EC2) showed cyclic behavior and were more important than fluctuations in the amount of chlorophyll-*a*. The latter parameter in the euphotic zone also showed cyclic behavior, correlated to temperature ($r = 0.46$), which was not reflected by the EC2 due to the great variability introduced into the data by the phytoplankton bloom of January.

The variations in the amount of each zooplankton species were irregular and many species were present all the year round. In spite of these irregularities, the PCA identified groups of species with different behavior in relation to the period of abundance.

The species of the ZC1 positive pole were more abundant during early fall and summer. Among them, the subtropical copepods *Paracalanus crassirostris* and *Corycaeus amazonicus*, the appendicularian *Oikopleura* sp., and seven meroplanktonic groups (cypris, decapods, polychaetes, cyphonautes, bivalves, gastropodes, and eggs and larvae of fish) were the taxa that more clearly showed this pattern. In Lagoa dos Patos (southern Brazil), Montu (1980) also found a greater abundance of these groups (except for *P. crassirostris*) in the hot season. The other species of the ZC1 + pole also showed large numbers in other monsths: the copepod *Hemicyclops thalassius* and the chaetognaths *Sagitta* spp. in July, related to the inflow of coastal waters; the copepods *A. tonsa* and *Euterpina acutifrons* were abundant all the year round except in spring, when zooplankton decreased due to the abundance of tentaculate ctenophores.

In contrast to this group, the negative pole of the ZC1 selected the cladoceran P. *polyphemoides*, which was present in late fall-winter. This species is a low salinity indicator which was present mainly in the surface waters of the River Plate. This is suggested by several observations: (a) it was recorded during the period when waters are stratified; (b) its maximum abundance occurred on the first sampling day of August, when low salinity water (20°/₀₀) occupied all the water column; and (c) on the next day there was an inflow of saline water (29°/₀₀) at the bottom, and the numbers of this cladoceran decreased. This opposition between coastal and estuarine species depends on water circulation, as shown by the correlation between ZC1 and EC1.

The ZC2 selected species which were present mainly in fall. Among them, rotifers were brought in by the River Plate waters, and the others were subtropical copepods. Some of the latter reach the Buenos Aires Province (northern Argentina) only in early fall (*Centropages velificatus* and *Eucalanus pileatus*) (Ramirez, 1977), or are present in the area the year round, but their maximum abundance is in May (*C. amazonicus*) (Ramirez, 1969).

On smaller space and time scales, the differences pointed out by the components are the result of biological or advective processes. These processes may develop only in the Bay, only at the Exterior station, or in both. Also the conditions at each station may change in one day. An example of small-scale variability due to biological processes is the phytoplankton bloom of January, which developed only in the River Plate and vanished one day after. This phenomenon was reflected by several components, mainly by the EC4 (chlorophyll-*a*), EC3 (phytoplankton pigments) and ZC3 (zooplankton). In the EC3, the total pigments/chlorophyll-*a* quotient (DD) is the variable responsible for the January peak. High values of this quotient are associated with poor physiological conditions of the phytoplankton and/or the presence of detritus in the seston (Margalef, 1963). It is very likely that the former condition occurred during the bloom, because evidence of self-shading was recorded (reduced transparency in the bloom area).

Advective processes account for most of the differences on small scales during stratified periods. For example, on the first sampling day of May, there were differences between stations in the environmental parameters (EC1, EC3) but not much in zooplankton (ZC1, ZC2); on the second day conditions in the Bay were about the same, but surface waters at the Exterior station changed (EC2), as did zooplankton at this station (ZC2, ZC3). Another type of advective process occurred in July and August, and was reflected by the EC1, ZC1 and ZC3. In July, on the first day waters were stratified at both stations, but in the Bay bottom salinity was lower than in the Exterior station; the second day salinity of bottom coastal waters increased at both stations, haloclines occurred nearer to the surface than in the previous day, and zooplankton changed at both stations but more at the Exterior one. In August the events were similar, except that on the first sampling day estuarine low-salinity waters occupied the entire water column at both stations, and the environmental changes were more pronounced at the Exterior.

This study underlines the fact that in Maldonado Bay, as probably in other highly variable aquatic environments, variations on different space and time scales overlap, and the main factors involved are different on each scale.

Acknowledgements

This paper is part of the author's Ph.D. thesis at the Oceanographic Institute of the University of São Paulo, under the advisorship of Dr Alfredo Martins Paiva Filho.

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(Received 17-Mar-1986; accepted 18-Aug-1986)