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Eutrophication of Sediments in the Cullera Bay: Composition and Abundance of Macrobenthos

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ABSTRACT

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Nutrient retention in estuaries and semi-enclosed bays is a principal contributing factor to the relatively high production of these marine systems. Cullera bay occasionally presents serious environmental problems owing to discharge of the Júcar freshwater, sewage from a marine outfall and nutrients release of the sediment. This study examine the macrobenthos in order to evaluate their composition and abundance in anthropogenically impacted coastal sediments and waters. A total of five field campaigns were carried out during years 2002-2003, but, in this paper, we shown the results of the first campaign. The macrobenthos was collected at twelve stations along three transects using a type of Peterson grab, but only we have used the bivalve molluscs because they represent most benthic biomass. To evaluate the influence of environmental factors on the bivalves, we took undisturbed sediment and bottom-water samples at fourteen stations. In water samples we have studied salinity, nutrients, chlorophyll *a* and suspended solids, and granulometry, organic matter, total nitrogen and total phosphorous in sediment samples. In general exists a high organic matter accumulated in sediments of the bay that increases with depth. The concentration of nutrients of the waters are low, however, the concentration of chlorophyll *a* suggests a eutrophic character of the shallowest zones. Although bivalve density do not show a clear pattern with every parameters measured, we find some relationships between most abundant bivalves *(Donax* spp. and *Spisula subtruncata*) and depth, chlorophyll *a* of waters and granulometry and nutrients of sediments.

ADITIONAL INDEX WORDS: *Bivalves, Nutrient, Donax, Spisula subtruncata.*

INTRODUCTION

Eutrophication has been defined by WELCH (1992) as the process by which water bodies become more productive through increased input of organic nutrients. Moderate increase in limiting nutrients leads to increased primary production (phytoplankton and macroalgae) that may have positive effects on benthic communities. Because enhance primary production, it is assumed that macrobenthos responds to better feeding conditions by faster rates of growth and higher productivity (BEUKEMA and CADEE, 1986; BEUKEMA, 1991). When the nutrient levels overwhelm the capacity of a system to assimilate them, eutrophic conditions can have negative effects on benthic communities (KENNISH, 1997): changes in species composition and changes in the behavior of species sensitive to reduced oxygen concentrations (DAUER and ALDER, 1995). During extreme eutrophic events may occur anaerobiosis and kills masses of benthic and epibenthic organisms (NIENHUIS, 1993; ROSENBERG and LOO, 1988).

Several biological assemblages have been monitored to assess the effects of organic pollution (SMITH *et al.,* 1999; GUIDETTI *et al.,* 2002). However, the bulk of available information derives from studies on soft-bottom communities (AUSTEN *et al.,* 1989). Furthermore, WARWICK (1993) explains advantages in using soft-bottom communities for biomonitoring: they are easier to sample quantitatively and show detectable responses to anthropogenic impact. For this paper, we only have used the bivalve molluscs because they are easily identified and represent most benthic biomass (SHELTON and ROBERTSON, 1981).

As a consequence of their vicinity on the land, Mediterranean littoral systems receive large amounts of organic and mineral nutrients derived from urban, agricultural and industrial effluents. Most of the deposited organic matter is degraded at the sediment-water interface or in the upper sediment column (JOGERSEN, 1983). The importance of benthic sediment in controlling nutrient concentrations in overlying waters has long been a subject of concern. WALSH (1991) reported that sediments are important sites for recycling nutrients back to the water column, thus influencing global nutrient cycles. According to KLUMP and MARTENS (1983), the benthic nutrient flux can exert a major control on pelagic productivity, supplying 50 % or more of the nutrient requirements and influencing the trophic status of the system. Thus, sediment nutrient release may have a significant impact on the water quality and result in continuing eutrophication even after point sources of nutrients have been substantially reduced.

The main objective of this work is to analyze the changes in the most abundant species of macrobenthos in space, trying to evaluate possible relationships among faunistical features, natural and man induced water and sediment characteristics, by means of correlative methods.

STUDY AREA

Cullera bay is situated on the Spanish Mediterranean coast (Figure 1). It is delimited by the cape of Cullera in a northward direction and the river Júcar in a southward direction. The geographical configuration of Cullera bay and the activities of humans hinders the circulation of the waters.

Because it receives heavy inputs of nutrients originating from the river Júcar and the marine outfall, the bay presents serious environmental problems that are aggravated during the summer, when the Cullera population increases to 350.000 inhabitants. As a result of the river nutrient load and the sewage from the city of Cullera, the bay is mostly eutrophic (DEL RÍO, 1986; SOLER *et al*., 1988; SOLER and DEL RÍO, 1996). Furthermore, the bay support artisanal bivalve fisheries (*Chamealea gallina* and *Donax* spp.).

Table 1. *Data relative to sampling depth and granulometry.*

	Depth	Granulometry (%)						
	(m)	-1	0	1	2	3	4	5
M1	6.8	0.38	0.76	6.15	6.83	39.27	43.72	2.89
M2	9.5	0.67	1.74	3.44	5.13	34.52	52.76	1.83
M4	6.8	4.43	1.02	1.66	3.95	60.91	26.77	1.22
M5	11.5	71.66	20.16	6.58	1.05	0.20	0.29	0.08
M6	11	1.04	0.95	1.51	3.38	45.36	46.82	0.91
M8	2.8	1.82	0.29	0.86	5.19	69.76	21.78	0.31
M9	5.5	0.42	0.17	0.58	2.06	70.69	25.63	0.43
M10	9	1.32	0.31	0.78	2.14	39.99	53.73	1.68
M11	6.5	0.35	0.39	0.98	2.80	56.10	35.48	3.95
M12	3	0.81	0.30	1.08	5.97	80.62	11.16	0.06
M13	2.5	0	0.20	1.74	16.80	72.95	8.27	0.06
P5	1	0.71	0.24	0.44	5.02	81.16	12.35	0.10
P8	1	1.32	0.88	2.53	18.64	66.12	10.56	0.04
P11	1	0.06	0.20	1.02	12.66	80.83	5.19	0.02

MATERIALS AND METHODS

Sampling

The benthic macrofauna, sediments and waters were sampled in July, September and November 2002, and February and April 2003. In this paper, we present the results corresponding to the July 2002 campaign. The macrobenthos was collected along three transects at 1, 3, 7 and 10 m depths (P5, P8, P11, M1, M2, M4, M6, M8, M9, M10, M12 and M13 stations). Sediments and waters were sampled in the same stations plus M11 (outfall) and M5.

For the benthic communities study, six samples were taken at every station using a type of Peterson grab (0.06 m²). The benthic macrofauna was sieved through a 1 mm mesh size preserved in a formol seawater solution (5 %).

To evaluate the influence of environmental factors on the benthic communities, additional sediment samples (three undisturbed corers, Ø 0.6 m) were taken for analysis of grain size, organic matter, total nitrogen (TN) and total phosphorous (TP), and were frozen at 20ºC. At the same time, bottom-water samples were collected by plastic bottle for the determination of chlorophyll *a*, salinity, ammonium, nitrite, nitrate, reactive soluble phosphorous (RSP), total dissolved phosphorous (TDP), total phosphorous (TP), orthosilicic acid and suspended solids.

Laboratory Analysis

Biological Analysis

Bivalves were sorted in the laboratory using a magnifying glass, identified to the lowest possible taxonomic level and counted. Next the density was calculated.

Sediment Analysis

Sediment granulometry was carried out according to the BUCHANAN method (1984) using a sieve series. The organic matter content of the sediment was measured by the difference between the dry of the sample (105 ºC) and the weight after calcination for 1 hour at 600 ºC in a muffle furnace. The concentrations of TN and TP were determined according to methods of VALDERRAMA (1981), and analysed with an Alliance Instruments Evolution II Autoanalyser.

Water Analysis

The concentrations of nutrients viz. ammonium, nitrite, nitrate, RSP, TDP, TP and orthosilicic acid, were determined according to methods of TREGUER and LE CORRE (1975), considering PARSONS *et al*. (1984) and KIRKWOOD *et al*. (1991), and analysed with an Alliance Instruments Evolution II Autoanalyser. On the determination of chlorophyll *a* the trichromatic method was used, based on spectrophotometry (APHA, 1998). Salinity was measured with a Grundy Environmental Systems Inc. 6230 N induction conductimeter, calibrated with the suitable standards (I.A.P.S.O. Standard Seawater, Ocean Scientific International Ltd, K15= 0.99986, S= 34.995‰). Finally, the concentration of suspended solids was determined by the difference between the 0.45 ìm Nuclepore membranes and the weight after dried for 24 hours at 105ºC.

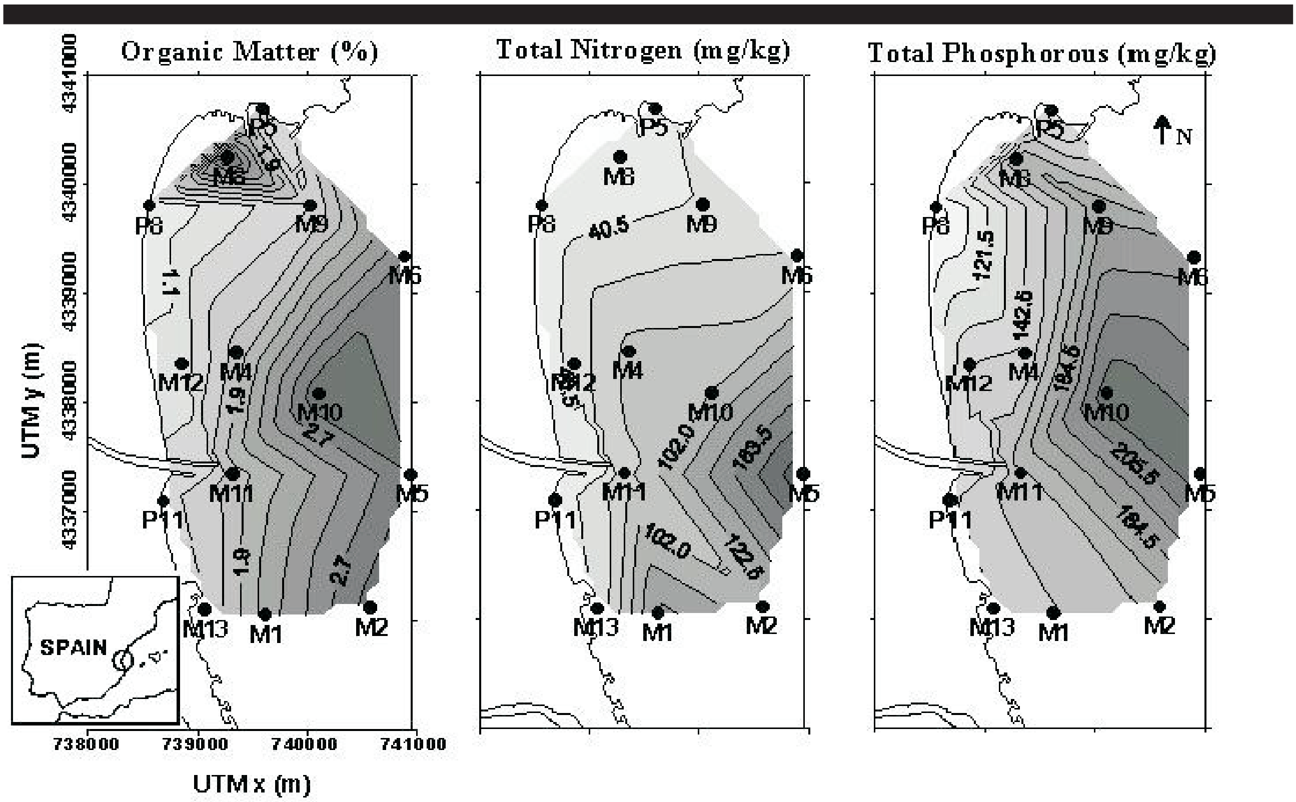

Figure 1. Study area and spatial distribution of organic matter, total nitrogen and total phosphorous concentrations in sediments.

Statistical Analysis

A correlation analysis was performed on the data set. Biological data were $log_{10}(x+1)$ transformed.

RESULTS AND DISCUSSION

Sediments Features

Data relative to grain size (Φ notation) and depth are showed in Table 1. Sediment grain size shows quite similar trends along the different transects, decreasing with depth. Sandy fraction dominates at all the stations, representing over 90%, while silt/clay fraction reaches its maximum percentages at the deepest stations. In exposed sandy beaches, the decrease of the hydrodynamism with the depth explains the accumulation of smaller size particles at the deepest stations. Only we find an exception, at the station M5 appears a large percentage of very coarse sand and granules. It is a zone subject to bottom currents that difficult the sedimentation of smaller size particles.

Data relative to organic matter content, Total Nitrogen (TN) and Total Phosphorous (TP) are represented in Figure 1. Organic matter content increases with depth, ranging on average between 1.2 % (1 m) and 2.9 % (10 m). Furthermore, a big accumulation appears at station M8. Sedimentation is seen favored in greater depth zones, where the waves are attenuated. This explains the greater organic matter accumulation in these places. At the station M8, it can be consequence of geographical configuration of Cullera bay, where the cape hinders the circulation of the waters and the sedimentation is favored.

In general, exists a high organic matter content accumulated in the bay, as compared with the results of the other studies in the Mediterranean sea (TIRADO and SALAS, 1999; SARDÁ *et al.,* 2000*)*.

TN concentrations follows the same increasing pattern with depth observed in the organic matter content, and to the South too. Maximum values are observed at 10 m depth (on average 124.4 mg/kg) and minimum values at the shallowest stations (on average 29.4 mg/kg). This trend seems to be related with grain size: in fact, NT concentration is significantly correlated ($P<0.01$) with silt/clay fraction ($r=0.97$; $n=12$). TP concentrations increase with depth and at the station M8, just like the organic matter content. In fact, TP concentration is significantly correlated ($P<0.01$) with organic matter content ($r=0.79$; $n=12$). Maximum values are observed at 10 m depth (on average 201.1 mg/kg) and minimum values at the shallowest stations (on average 120.0 mg/kg).

Waters Features

Data relative to salinity, ammonium, nitrite, nitrate, reactive soluble phosphorous (RSP), total dissolved phosphorous (TDP), total phosphorous (TP), orthosilicic acid, chlorophyll *a* and suspended solids are showed in Table 2 .

Minimum values of salinity appear at the shallowest stations and, above all, at the stations P11 and M13. In our opinion this is due to the closeness of the Júcar river. The river freshwater is mixed with the bay's seawater by the wavefield.

In general, the concentration of nutrients are low over the entire study area and little differences are found when compared to the results of the other studies in the Mediterranean sea (FABIANO *et al*., 2001; PUIGSERVER *et al*., 2002) and values are similar to those of oligotrophic Mediterranean sea (ESTRADA *et al.,* 1985).

RSP, TDP, ammonium and nitrite concentration shows a decreasing pattern from southern to the northern stations. The greatest ammonium and PSR concentration indicates high rates of mineralization of the organic matter. The decomposition of the organic matter accumulated in the sediments releases nutrients to the water that is situated on them. This result is in agreement with the study of MWASHOTE and JUMBA (2002) which stress that the sediments in the Gazy bay (Kenya) act as a net source for ammonium and nitrite. The greatest nitrite concentration indicates high rates of ammonium nitrification.

The highest concentrations of nitrate, TP and orthosilicic acid are observed near station P11. This values observed in the bay coincide with the drop in the salinity indicating that their origin are the continental waters. In fact, salinity is significantly correlated ($P<0.01$) with nitrate ($r=-0.71$), TP ($r=-0.71$) and orthosilicic acid ($r=-0.72$).

Concentration of chlorophyll *a* ranged from 0.83 to 9.01 mg/m^3. It is appreciated a decrease of the concentration at the deepest stations, these assemblage agree with salinity and some nutrients (nitrate, TP and orthosilicic acid). When salinity decreases and the concentration of nutrients increases, concentration of chlorophyll *a* increases as well. This indicates that the principal source of nutrients for the phytoplankton proceeds from the continental waters. For example, freshwater incidence on phytoplankton community has been related to growth of *Clorophyceae* (PUIGSERVER *et al.,* 2002).

Although concentration of nutrient suggests a oligotrophic character, concentration of chlorophyll *a* suggests a eutrophic character of the shallowest zones (PUIGSERVER *et al.,* 2002). In the outermost area, values are similar to those of open Mediterranean sea (ESTRADA *et al.,* 1985)

Suspended solids concentrate on the center of the bay and it doesn't show a clear pattern with depth. The highest concentration is observed at station M4, but we don't find a clear distribution.

Bivalve Mollusk Composition and Abundance

Data relative to bivalves density and number of species are shown in Table 3.

Ten bivalve species were recorded from the study area during

Table 2. *Data relative to salinity and concentration of ammonium, nitrite, nitrate, RSP, TDP, TP, orthosilicic acid, chlorophill a and suspended solids of waters.*

	Salinity (‰)	Ammonium (μM/l)	Nitrite (μM/l)	Nitrate (μM/l)	RSP (μM/l)	TDP (μM/l)	TP (μM/l)	Orthos.A. (μM/l)	'Chl. *a* (mg/m³)	Susp.S. (mg/l)
M1	-	2.0	0.24	2.0	0.42	-	-	2.2	-	-
M2	37.53	0.3	0.03	1.0	<0.03	<0.03	<0.03	2.4	1.03	11
M4	37.48	0.1	0.05	0.6	<0.03	<0.03	0.18	3.1	3.19	51
M5	37.51	0.2	0.06	1.0	<0.03	<0.03	<0.03	1.9	0.83	12
M6	37.47	0.2	<0.01	0.3	<0.03	<0.03	<0.03	1.6	1.69	10
M8	37.23	0.3	<0.01	0.4	<0.03	<0.03	0.06	2.4	2.22	23
M9	37.74	<0.1	0.02	1.0	<0.03	<0.03	0.07	1.8	1.17	11
M10	37.54	0.6	0.02	0.2	<0.03	<0.03	0.03	2.0	2.00	16
M11	37.40	1.4	0.05	0.6	<0.03	<0.03	0.14	3.0	2.03	32
M12	37.07	0.1	0.04	0.1	<0.03	<0.03	0.06	3.1	3.40	13
M13	36.93	0.5	0.16	2.1	<0.03	<0.03	0.16	3.1	9.01	28
P5	37.27	<0.1	<0.01	0.8	<0.03	<0.03	0.09	1.7	3.93	25
P8	37.39	<0.1	<0.01	0.8	<0.03	<0.03	0.15	1.8	3.78	18
P11	36.57	<0.1	<0.01	3.6	<0.03	<0.03	0.34	3.8	5.24	11

Table 3. *Data relative to bivalves species number and density.*

	Number of species	Density (ind/m²)	Density genus *Donax* (ind/m²)	Density *Spisula subtruncata* (ind/m²)
M1	6	736	13	697
M2	7	161	<3	94
M4	7	1542	5	1422
M6	6	514	5	458
M8	7	2014	1897	66
M9	7	7061	5	6986
M10	4	372	<3	358
M12	4	792	752	5
M13	2	608	588	<3
P5	6	500	441	27
P8	1	69	69	<3
P11	1	119	119	<3

this survey. Most of these species were only found at a few stations, and in low number. This is due to our method of sampling, we take known surface samples to carry out a quantitative analysis. In spite of the low number, we have found a correlation significant ($P<0.10$) between number of species and depth ($r=0.55$; $n=12$). The exposed sandy beaches of the world represents for their fauna high energy environments dominated by the physical processes of wave action. A few genus of molluscs, crustaceans and polychaetes dominate such environments, each one adapted to exploit actively the apparently severe conditions (ANSELL, 1983). In general, at the shallowest stations, with the highest severe conditions, appears the lowest number of species. At the station P5, the number of species increases owing to its location, this station is localized in the northern part of the bay where wave action decreases.

Density values of bivalves do not show a clear pattern with depth. Only we observe that the density is smaller to 1 and 10 m, and it increases to 3 and 7 m. We think this is the result of adverse local conditions, the highest hydrodynamism at the shallowest stations and the lack of food at the deepest stations. The station M9 presents the highest density, mainly due to the presence of large individuals of *Spisula subtruncata*. We haven't found any clear correlation between density of bivalves and the parameters measured in sediments and waters. From our point of view, this is difficult because ecological requirements of bivalve molluscs are very different.

The genus *Donax* and *Spisula subtruncata* are the most abundant bivalve species recorded. Bivalves of the genus *Donax* are suspension-feeders on phytoplankton and suspended particulate organic matter (MOUËNZA and CHESSEL, 1976). This basically determines which normally inhabits the wash zones of the beaches, where hydrodynamism favours the presence of suspended particles and impedes rapid sedimentation of the organic matter (MANCA *et al.,* 2002) and eutrophic conditions lead to high levels of phytoplankton production (ANSELL, 1983). Our results agree with it, the greatest density of genus *Donax* appears at the shallowest stations where hydrodynamism is most important. Furthermore, this zone is characterized by the maximum values of chlorophyll *a*, in fact, density of genus *Donax* is significantly correlated ($P<0.10$) with chlorophyll *a* concentration ($r=0.56$; $n=11$). We also have observed that density of genus *Donax* decreases when fine sand fraction increases and very fine sand and silt/clay fractions decrease.

Spisula subtruncata is a common bivalve which lives in coastal areas of Europe. It is suspension-feeder, just like genus *Donax*. However, the habitat of this species represents an environment where the percentage of fine particles is large and the hydrodynamism is less important. In the Cullera bay, density of *Spisula subtruncata* is significantly correlated ($P<0.05$) with percentage of very fine sand ($r=0.66$; $n=12$) and silt/clay ($r=0.58$; $n=12$). In this places, we have found the highest concentrations of TN and PT in sediments that apparently are correlated with presence of *Spisula subtruncata* too. Finally, we have found the most abundant density at stations M9, M4 and M1, where the concentrations of organic matter are similar, but not the highest. Probably, the appearance of this specie depend both a low hydrodynamism (greater percentages of smaller particle size) and a threshold of organic matter content.

CONCLUSIONS

Results of this study indicate that exist a big accumulation of organic matter in the bay, however, it is not influence in the concentration of nutrients. That shows that in the bay most mineralization and resuspension are not occurring, but in some places where the hydrodynamism increases, there are high concentrations of chlorophyll *a* that suggest a eutrophic character.

Although the method of sampling didn't allow us to obtain a large quantity of species and individuals, there were enough samples for our analysis. We think that is the best method to carry out a quantitative analysis.

We detect that the number of species increases with depth because the adverse conditions decrease. As a result of the different ecological requirements of bivalve molluscs, we haven't found significant correlations between density and parameters of sediments and waters. But, if we study the species separately, we will obtain more interesting results.

The highest densities of genus *Donax* appears where the concentration of chlorophyll *a* is greater and the depth and organic matter content are lower. However, the appearance of *Spisula subtruncata* depend both a low hydrodynamism and a threshold of organic matter content.

It is clear from the evidence presented here that there are very many factors affecting the distribution of organisms in sandy beaches. It also appears likely that the effect of some factors is modulated by other factors, resulting in a very complex set of interactions. We expect that analysis of the subsequent campaigns help to explain the causes underlying the abundance and the composition of macrobenthos.

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