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CARTOGRAPHY OF THE SURFACE SEDIMENTS OF THE RÍA DE FOZ (LUGO, NORTHWEST SPAIN) AFTER THE CONSTRUCTION OF A JETTY

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Keywords:Ría de Foz, cartography, sediments, jetty, coastal engineering , *Zostera noltii*

ABSTRACT

The changes in the cartography of surface sediments of the Ría de Foz (Northwest Spain), after the construction of a jetty in the mouth of the estuary are analysed in this work. A comparison of 2002 versus 1984-1985 cartography shows changes in the inner sandy banks of the Ría, with an increase of the pelitic and organic matter contents of the sediments. These changes are probably due to modifications of the hydrodynamic regime that also have promoted the enlargement of the area ocuppied by *Zostera noltii*.

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INTRODUCTION

The Ría de Foz (Lugo, Northwest Spain, 43º 34 ' N; 7º 14' W) has experienced in the last half century a series of harbour works and coastal defences that have altered the mouth of this estuary. Most of these works were designed to facilitate the access to the Foz's harbour, due to the instability of the entrance channel that varied its course and diminished its depth. In order to stabilize this access, a training wall was built in the left margin in 1973, which was prolonged in 1977. As a result of this construction, the eastern sand spit that extended from Punta Anguieira disappeared in 1978, opening more the mouth of the estuary and increasing the annual rate of sedimentary infill (Díez González, 1996).

It is in this state, with the disappeared spit, when Junoy and Viéitez (1989) mapped the surface sediments of the Ría, as a part of a study of the intertidal macroinfauna (Junoy and Viéitez, 1990, 1992; Junoy, 1996).

After this study, and due to the erosive processes that were taking place in the eastern side, diverse coastal engineering measures were taken within the "Plan de defensa y regeneración costera de la playa de San Cosme de Barreiros" (MOPU, 1985) during 1986 to 1988. The aim of this plan was to control both the problem of sediment accretion in the inner parts of the Ría and that of the acute erosion of the Playa de Anguieira. A part of this project was the construction of a jetty, or hook groyne, to retain and support the sand. In order to regenerate the growth of the spit and beaches, sands dredged from the inner parts of the Ría were relocated to artificially refill the areas affected by erosion. Details on the evolution of the mouth morphology are showed in Castellanos et al. (2003).

In order to evaluate the impact of the construction of this jetty and of the dredging process, the present work focuses on the changes in the cartography of surface sediments before and after these works, taken the data from Junoy and Viéitez (1989). Studies in the macroinfaunal changes have been presented elsewhere (Castellanos et al., 2003).

MATERIAL AND METHODS

The sampling programme was adjusted to provide adequate information on the sediment distribution, and consisted of 45 sample points widely distributed throughout the Ría (Figure 1). These points were sampled between the 25th and the 29th January 2002.

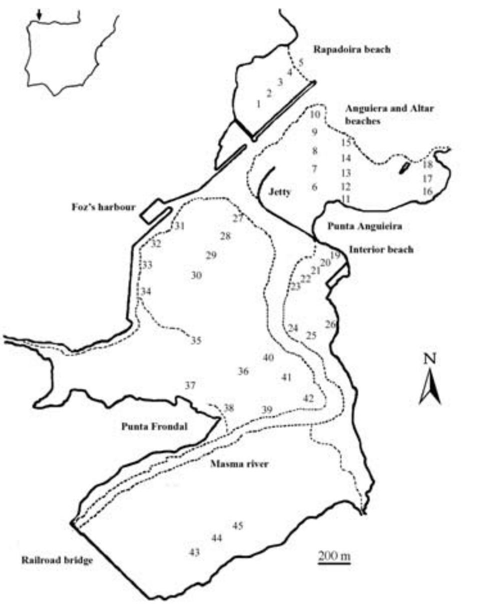

Figure 1.
Map of Ría de Foz with the location of samples taken in the Ría de Foz in January, 2002.

One sampling campaign was considered sufficient due to the stability of the sediment characteristics, which had not suffered significant changes throughout the year in the previous study (Junoy and Viéitez, 1989).

Samples were taken with a PVC tube, 6 cm diameter, until a depth of 15 cm. The sediment was labelled and kept in plastic bags until its arrival to the laboratory, where it was dried in a stove at 60º C.

Particle size analysis was performed by dry sieving (Buchanan, 1984). Organic matter content of the fraction of the sediment < 0.5 mm was estimated as weight loss of dried samples after combustion (450 ºC, 24 h). For each sediment sample the percentage of each sedimentary fraction, the median size grain diameter (Md), the sorting coefficient (So), the sedimentary type and the content of organic matter were calculated (see Junoy and Viéitez, 1989 for details). The percentage of each sedimentary fraction and the organic matter content were used to compute Bray-Curtis similarity coefficients for all samples; hierarchical agglomerative clustering of the matrix of Bray-Curtis similarity coefficients was used to quantify associations between samples. .

To evaluate the cartographic evolution of surface sediments from the construction of the jetty, a comparative analysis was made between the samples collected in December 1984 (31 samples), March 1985 (25 samples) and January 2002 (45 samples). A matrix of 101 samples was obtained an analysed using the procedures described before. The similarity matrix showed a great homogeneity between samples of the same area. For this reason, fourteen stations (Figure 2) that had been sampled in the three campaigns (December 1984, March 1985, January 2002) were selected to facilitate the exposition. These fourteen stations were representative of the following areas: a) Beaches, three stations located in Anguieira, Altar and Interior beaches (stations P1, P2 and P3); b) Pier, three stations located on the left margin of the Ría, parallel to the pier of Foz's harbour (stations M1, M2 and M3); c) Channel, three stations located on the right margin of the Ría, in a transect perpendicular to the channel of the Masma river at low tide (stations C1, C2, C3); d) Frondal, three stations located in sandy banks situated in front of Punta Frondal (stations F1, F2 and F3); and e) Inner, two stations located in the inner part of the

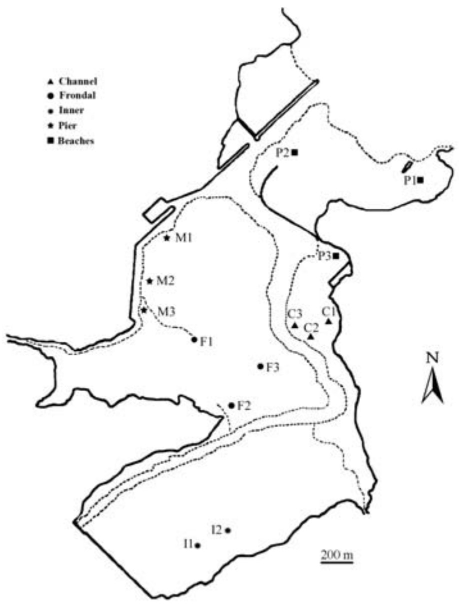

Figure 2.
Map of Ría de Foz with the location of the fourteen sampling stations. Years 1984, 1985 and 2002.

Ría, in front of the railroad bridge (stations I1, I2). This set of samples was again analysed using the same procedures described before. Table 1 shows the samples' code numbers and their respective stations.

RESULTS

January 2002 campaign

Table 2 shows the percentage of each grain size fraction the median grain size, the sorting coefficient and the organic matter content of the 45 samples collected in January 2002.

A positive gradient of organic matter content exists towards the inner part of the Ría, so that the highest values are in the most internal and fluvial parts and the lowest values are in the most external and oceanic areas. A distribution map of the organic matter content of surface sediments is showed in Figure 3. This distribution is very similar to that observed for the pelitic fraction, existing a close correlation between both variables ($r = 0.95$; $p < 0.01$).

The gravel fraction (> 2 mm) only reaches high values in points on the right margin of the Ría where the bottom has been artificially refilled to favour the culture of molluscs, peaking in Sample 25 at 42.54 % of the sediment. The very coarse sand (2-1 mm) and the coarse sand (1-0,50 mm) fractions, whose joint distribution is showed in Figure 4, appear mainly in the mouth of the Ría, where they constitute more than 10 % in five samples. The medium sand (0.50-0.25 mm) is the more important grain size fraction of the bottoms located ahead, towards the sea, of Punta Frondal. This fraction is higher than 50 % in twenty-eight samples,

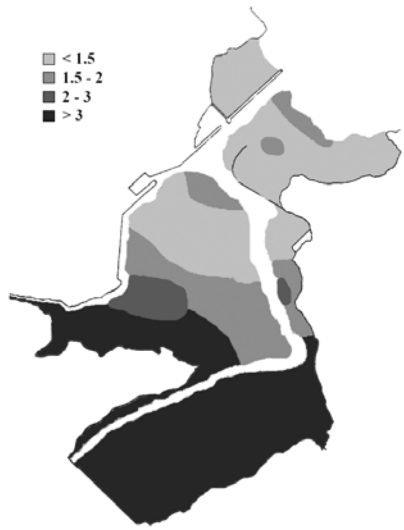

Figure 3.
Map of the percentage of organic matter in the surface sediments, January 2002.

Table 1.
Denomination of the samples collected in the 14 stations in 1984, 1985 and 2002. With asterisk, samples from January, 2002.

	Beaches			Pier			Channel			Frondal			Inner	
	P1	**P2**	**P3**	**M1**	**M2**	**M3**	**C1**	**C2**	**C3**	**F1**	**F2**	**F3**	**I1**	**I2**
1984	27	28	34	37	38	31	83	70	33	86	85	69	96	95
1985	56	44	49	52	53	47	88	74	48	90	89	73	99	98
2002	17*	9*	19*	31*	33*	34*	26*	25*	24*	35*	38*	36*	44*	45*

Table 2.
Grain size fractions, expressed in percentage of total, median grain size (Md), sorting coefficient (So) and percentage of organic matter (o. m.) of the 45 samples from January, 2002.

	% Sedimentary fraction									
Sample	**> 2**	**2--1**	**1-0.5**	**0.5-0.25**	**0.25-0.125**	**0.125-0.063**	**< 0.063**	**Md**	**So**	**o. m.**
1	2.68	1.18	6.03	69.33	18.48	0.47	1.83	0.34	1.34	1.29
2	1.93	5.41	11.85	71.04	9.3	0.03	0.44	0.39	1.25	1.14
3	0.25	1.18	9.27	63.42	24.46	0.16	1.24	0.36	1.34	1.48
4	0.64	2.58	12.97	67.11	15.35	0.04	1.31	0.37	1.29	1.36
5	0.12	0.64	6.17	73.6	18.11	0.12	1.43	0.35	1.28	1.38
6	0.2	0.7	3.48	67.48	27.62	0.06	0.46	0.33	1.34	0.86
7	0.11	0.74	4.49	57.39	35.54	0.14	1.71	0.3	1.41	1.53
8	0	0.06	0.8	67.65	30.26	0.06	1.66	0.32	1.35	1.1
9	0.57	2.09	14.77	75.14	6.01	0.01	1.8	0.39	1.24	1.37
10	0.01	0.14	1.64	55.38	41	0.03	1.8	0.28	1.42	1.54
11	0	0.06	2	67.92	28.78	0.02	1.22	0.32	1.34	1.07
12	0.05	0.11	2.26	58.8	36.7	0.37	1.71	0.3	1.4	1.5
13	0	0.09	1.71	73.93	23.82	0.04	1.66	0.34	1.3	1.13
14	0.01	0.18	4.32	76.33	17.46	0.04	1.66	0.35	1.26	1.49
15	0.06	1.12	7.23	64.31	25.51	0.16	1.61	0.34	1.35	1.59
16	0.01	0.26	2.64	57.01	38.83	0.08	1.17	0.29	1.41	1.27
17	0.01	0.09	1.13	52.38	44.77	0.18	1.44	0.27	1.42	1.46
18	0.02	0.16	1.13	45.64	51.46	0.15	1.44	0.24	1.42	1.28
19	0.29	0.56	3.62	73.92	20.28	0.08	1.25	0.35	1.28	1.25
20	0.02	0.03	0.46	67.47	30.74	0.1	1.18	0.32	1.36	1.12
21	0.04	0.05	0.56	56.26	41.21	0.17	1.71	0.28	1.41	1.1
22	0.14	0.85	3.45	55.25	38.62	0.27	1.42	0.29	1.42	1.34
23	0.61	2.33	10.02	72.29	14.01	0.08	1.93	0.37	1.26	1.31
24	0.18	0.23	1.06	27.08	66.76	2.76	1.93	0.21	1.31	1.62
25	42.54	2.65	1.36	7.05	30.16	8.62	7.62	0.38	7.38	2.78
26	1.57	0.9	0.91	27.27	59.3	5.21	4.81	0.21	1.38	1.57
27	0	0.05	0.59	41.5	55.94	0.35	1.37	0.23	1.41	1.59
28	0.08	0.32	4.83	76.74	16.1	0.15	1.93	0.35	1.26	1.61
29	0.5	1.61	9.03	72.31	13.78	0.69	2.08	0.37	1.27	1.23
30	0.01	0.12	2.37	71.6	24.44	0.1	1.46	0.33	1.31	1.39
31	0.14	0.7	7.9	83.16	7.71	0.05	0.34	0.37	1.22	1.21
32	0.13	0.83	8.76	83.01	5.81	0.03	1.43	0.38	1.22	1.31
33	0.02	0.17	2.57	63.75	31.68	0.09	1.72	0.31	1.38	1.89
34	0.22	0.5	2.81	59.01	32.77	2.34	2.35	0.3	1.42	1.7
35	0.03	0.27	0.55	28.29	48.1	11.38	11.38	0.2	1.48	2.58
36	0.33	1.16	1.16	15.99	27.52	16.61	37.23	0.11	4.7	6.9
37	0.26	0.57	0.47	3.78	15.85	28.31	50.76	0.06	-	7.34
38	0.38	0.41	0.66	18.07	36.83	17.13	26.56	0.15	2.08	3.3
39	0.53	0.38	0.93	23.21	45.53	12.61	16.81	0.18	1.56	3.47
40	0.06	0.18	0.8	35.48	53.64	4.82	5.02	0.22	1.43	1.86
41	0	0.12	0.84	31.09	63.65	2.12	2.18	0.21	1.36	1.74
42	0.05	0.87	4.07	42.8	49.24	0.8	2.17	0.24	1.45	1.79
43	5.56	2.5	1.73	4.62	14.11	17.79	53.69	0.05	-	4.89
44	1.37	0.6	0.71	3.94	19.86	25.49	48.03	0.07	-	5.68
45	0.67	0.28	0.53	3.54	14.04	21.6	59.34	0.03	-	6.83

with a maximum value of 83.16 % in Sample 31 (Fig. 5). The fine sand fraction (0.25-0.12 mm) acquires importance in the middle part of the Ría, constituting more than 50 % in four samples located in the sandy banks close to Punta Frondal, in the right margin of the inner Ría, and singularly, in a sample of the Altar beach (Fig. 6). The percentage of very fine sand (0.12-0.06 mm) is less than o 1 % in thirty-one samples, all of them located in front of Punta Frondal. This fraction reaches its maximum percentage, 28.31 % in Sample 37, close to Punta Frondal (Fig. 7). The pelites (< 0.06 mm) constitute the principal fraction of the sediments located between the Punta Frondal and the railroad bridge (Fig. 8).

The median grain size is between 0.39 mm and 0.25 mm in thirty samples, and < 0.25 in the remaining fifteen. This parameter diminishes from the mouth to

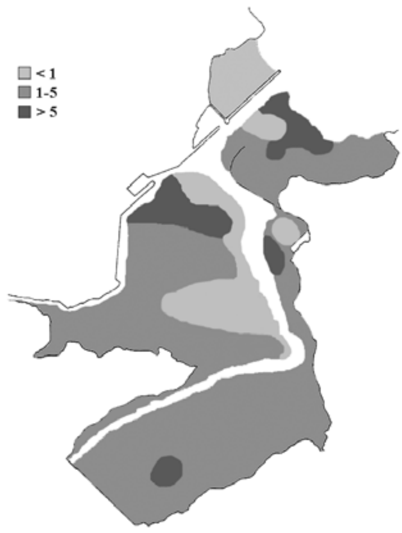

Figure 4.
Map of the percentage of very coarse sands and coarse sands in surface sediments, January 2002

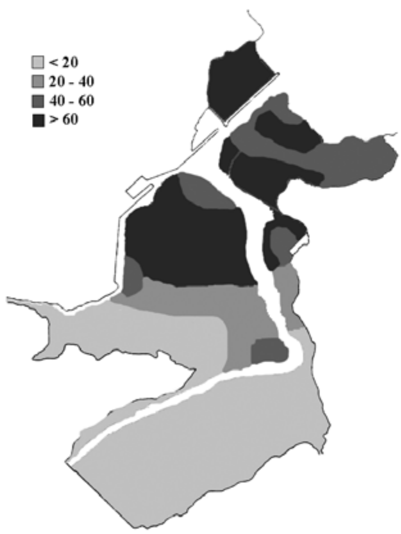

Figure 5.
Map of the percentage of medium sands in surface sediments, January 2002

the inner part of the Ría, according with the changes in the percentages of the sedimentary fractions. As revealed by the values of the sorting coefficient, the sediments are moderately well sorted (1.20 < So < 1.35) in nineteen samples, moderately sorted (1.35 < So < 1.87) in another nineteen, poorly sorted (1.87 < So < 2.75) in a sample (Sample 38), and very poorly sorted (So > 2.75) in other two samples (Samples 26 and 35). In the remaining four samples was impossible to determinate the sorting coefficient by the used method.

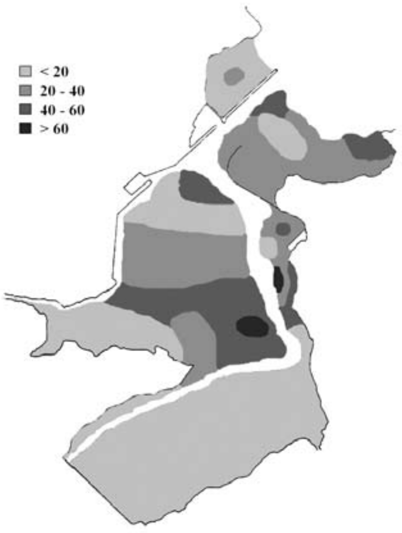

Figure 6.
Map of the percentage of fine sands in surface sediments, January 2002

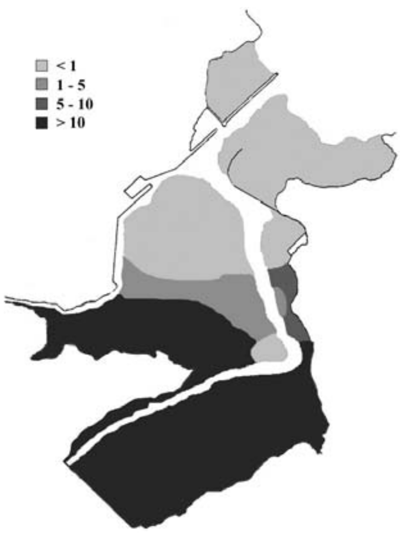

Figure 7.
Map of the percentage of very fine sands in surface sediments, January 2002

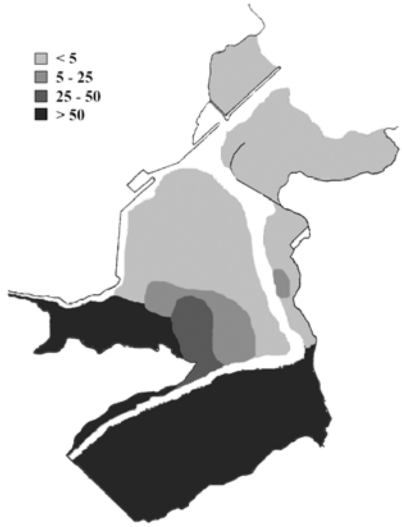

Figure 8.
Map of the percentage of pelites in surface sediments, January 2002

Five sedimentary types have been identified in the Ría de Foz: Medium sand, Fine sand, Silty sand, Sandy silt and Silt, as shown by the cluster analysis (Fig. 9). The distribution of the different sedimentary types in the Ría is shown in Figure 10, together with the distribution observed in the years 1984-85.

Comparison 1984-85 versus 2002

Figure 11 shows the result of the cluster analysis for the samples taken in the 14 stations during the three campaigns. Figure 12 shows the cumulative grain size curves of these samples, grouped by station areas.

The sedimentary characteristics of the stations of Beaches and Pier have remained relatively stable with time, with all the samples collected being very similar to each other. The sedimentary type is Medium sand (Md, Beaches, x = 0.31 mm; Pier, x = 0.30 mm) with low pelitic (Beaches, x = 1.30 %; Pier, x = 1.94 %) and organic matter (Beaches, x = 1.49 %; Pier, x = 1.68 %) contents.

On the contrary, in the stations of the Channel

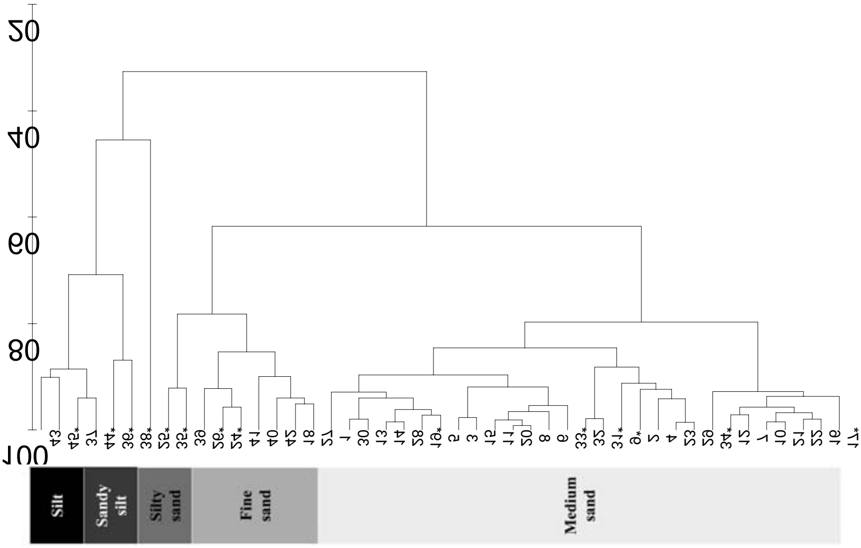

Figure 9.
Cluster analysis of the 45 samples taken in January 2002 and sedimentary characterization. With asterisk, the 14 samples used for comparison with years 1984 and 1985.

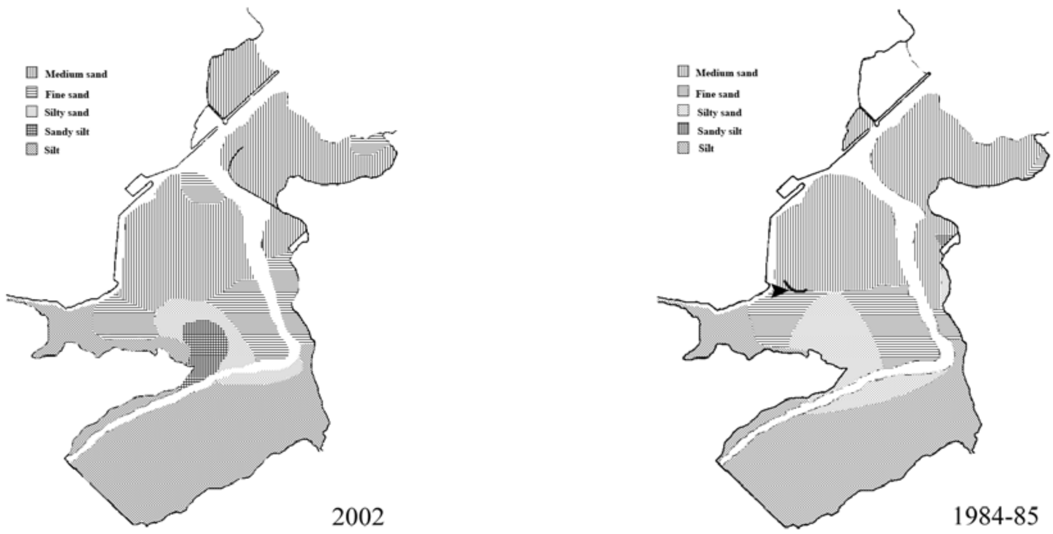

Figure 10.
Map of the sedimentary types. a) January 2002; b) 1984-85. Arrow: seawall (see text).

temporal changes can be observed. These changes affect the two stations next to the channel of the Masma river, with Station C1, next to the coast, remaining relatively stable, where Fine sand sediments were present in the three years (Md, x = 0.21 mm) with a pelitic content of 4.94 %. In 1984 and 1985, Medium sand sediments (Md, x = 0.28 mm) with low pelitic content (x = 1.6 %) were present at station C3, whereas in 2002, the sediment was of Fine sand type (Md = 0.21 mm) with a similar pelitic percentage (1.93 %). A

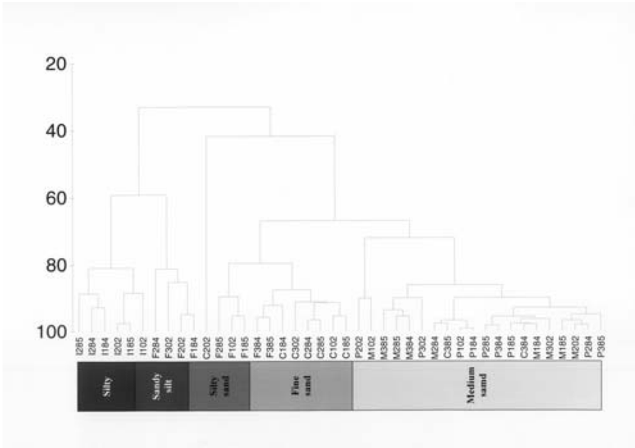

Figure 11.
Cluster analysis of the samples collected in the 14 stations during 1984, 1985 and 2002 sampling campaigns. Code: both first characters allude to the station, both last to the year.

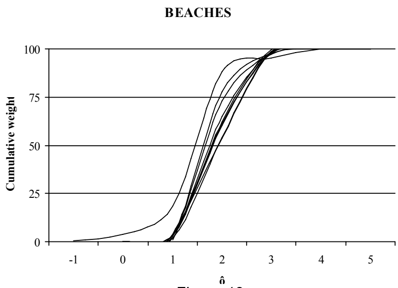

Figure 12.
a) Beaches;

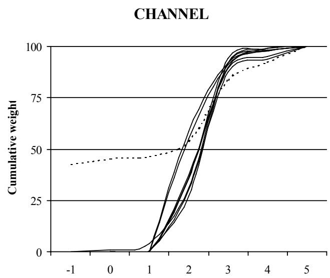

Figure 12
b) Pier

Figure 12.
Cumulative grain size curves of the samples collected in the 14 stations during 1984, 1985 and 2002. In order to facilitate graphical presentation of grain size frequency data, grade scale boundaries are logarithmically transformed into phi (?) values, using the expression ?= -log2 d, where d is the grain diameter in millimetres. Some curves have not been shown to clarify the presentation.

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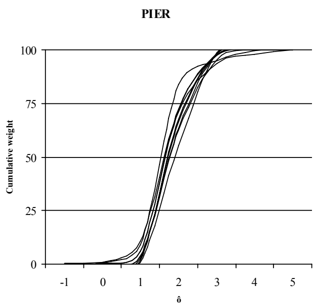

Figure 12.
c) Channel, in discontinuous line, sample C202;

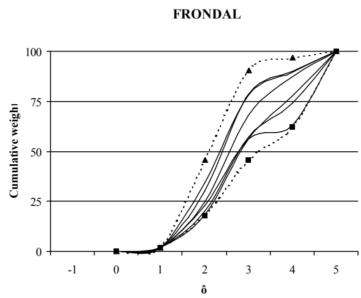

Figure 12.
d) Frondal, note the heterogeneity between the samples, and the change produced in the samples from F3 station, in discontinuous line: ?= 1984 and 1985; ¦ = 20022

e

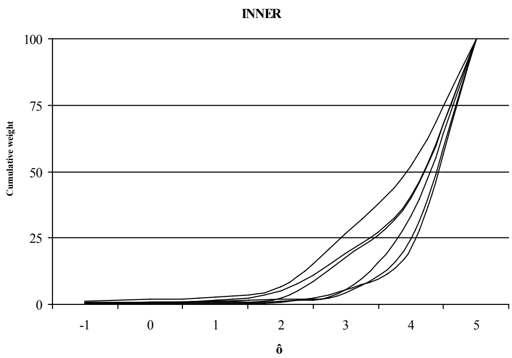

Figure 12.
e) Inner.

radical change is observed in the Station C2 due to an artificial preparation of the substrate for the bivalve culture. This area was filled with gravel, due to which the sample collected in January of 2002 is very different from those of the rest of the Ría (Fig. 12c).

The most spectacular change in the sediments of the Ría has taken place at Station F3 , located in front of Punta Frondal. Whereas in 1984 and 1985 the sediments was of Fine sand type (Md, x = 0.23 mm) with moderate pelitic (x = 3.06 %) and of organic matter (x = 1.93 %) contents, in January 2002 the sediment is of Sandy silt type (Md = 0.11 mm), rising the pelitic (37.23 %) and organic matter (6.90 %) contents (Fig. 12d). Also, organic matter rich Silt (max. 7.34 %) were detected in sample 37 in front of Punta Frondal, a situation that has not been observed in the previous campaigns.

All the samples collected in the stations of the Inner area are grouped together in the cluster analysis. They are sediments of Silt type with high pelitic and organic matter contents (% pelite, x = 64.65 %; % organic matter, x = 6.8 %), without noticeable changes since 1984-1985.

DISCUSSION

As pointed by Junoy and Viéitez (1989), the Ría de Foz shows the habitual sedimentary gradient of rías and estuaries, with sandy sediments in the mouth and muddy sediments in the interior part. This distribution responds to the different origin of the sedimentary materials and to the dynamics of the sedimentation processes. The sands, of marine origin, are located in the mouth, being dragged the finest particles towards the interior of the Ría. An increase of the fraction of very fine sands is thus observed in this way along the Ría. On the other hand, the pelites, of continental origin, are located inside the Ría and they accumulate under the most sheltered conditions of this area.

In any case, and although the general scheme before commented continues being valid 17 years later, our interest was to know how the jetty construction has been able to affect the sediment, to approach the effects on the macroinfaunal species and benthic communities (Castellanos et al., 2003).

The coastal constructions tend to alter the dynamics of sediments, changing the local hydrodynamic conditions (e.g. Vroon, 1994. For literature revision, see Kraus, 1988, and Kraus and McDougal, 1996). After the construction, in those places where these conditions are reduced, the finest particles of the sediment will be increased, whereas in the places where they are increased, they will be the coarse fractions those acquiring higher importance (e. g. Desprez and Dupont, 1986; Mulder and Louters, 1994).

With regards to the Ría de Foz, in the mouth (Beaches and Pier stations), sediment characteristics are similar to the found ones in the previous study. Sediment is Medium sand type, with low contents in the pelitic fraction and organic matter, as found in other beaches and estuaries of the Lugo coast (Mazé et al. 1989; Currás and Mora, 1991; Pérez Edrosa and Junoy, 1991, 1993).

A remarkable fact is the almost total burial of a rocky seawall that was at the end of the Foz's harbour. This seawall, patent during the 1984-85 sampling campaigns (see Figure 10b, arrow) was also appreciable in a later aerial photography (TOPONOVA, 1987). There has been a greater sand deposit that has caused their burial from these years to 2002.

On the right margin of the Ría, behind Punta

Anguieira, the artificial refills with gravel have caused a sedimentary change that has affected a very small area, due to the little magnitude of the filling. By the other hand, in this zone it has had to diminish the hydrodynamic conditions, because a diminution of the median grain size is observed.

The greatest change that has happened in these last years has taken place in sandy banks located in front of Punta Frondal, being observed an increase of the pelitic fraction and the organic matter content. Thus, the stations that in 1984 and 1985 displayed Fine sand sediments have happened to have Sandy silt sediments in 2002, whereas other zones that the sediment type was Silty sand have happened to be of Silt type.

The construction of the jetty of Punta Anguieira has created more protected conditions against waves and currents inside the Ría, which has facilitated the sedimentation of the pelites and the increase of the organic matter content. The reduction of the hydrodynamic conditions in this zone has caused the proliferation of the sea grass meadows of Zostera noltii, in such a way that the sedimentary change agrees with a bionomic change. Whereas in 1984 to 1987 a small meadow fragmented in two spots, was only in this sandy bank, occupying about 12,000 m2 (Junoy, 1996; own data), at the year 2002 the area that occupies is about 200,000 m2, extending along the right side of the sandy banks in front of Punta Frondal. This extension is the same one that was indicated by Laborda et al. (1997) for this meadow in 1994-1995. Thus, the expansion of the Zostera has had to happen between 1987 and 1994. This fact is not unusual, indicating Den Hartog and Polderman (1975) similar enlargement of the area occupied by Zostera associated to the reconstruction of a harbour in the Dutch Waddenzee.

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