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Spatial distribution of benthic macrofauna in subtidal sediments of the Ría de Aldán (Galicia, northwest Spain)

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SUMMARY: In the summer of 1997, 27 subtidal stations were quantitatively sampled in the Ría de Aldán. A total of 81770 individuals were collected, comprising 496 species. The distribution and composition of benthic assemblages was correlated to the sedimentary characteristics which, in turn, depend on the hydrodynamic features; those patterns are reflected in a sedimentary gradient present along the ria, which is characterized by an increasing grain size from the inner margins towards the mouth. Several faunal assemblages were determined through multivariate analyses and their composition is compared with that of several communities or facies previously described from similar sediments. The *Venus fasciata* community was present in clean coarse sediments of the outer ria, the *Venus gallina* and *Tellina fabula-Tellina tenuis* communities in the fine-sand bottoms at the centre and margins of the ria, a transition assemblage between the *Venus fasciata* and the *Venus gallina* communities in the medium-sand sediments, and a mix of species from the *Syndosmya alba* and the *Amphiura* communities in shallower and muddy sediments in the inner areas. In general, subtidal sediments of the Ría de Aldán showed a high benthic diversity which is related to the great sedimentary heterogeneity and the lack of significant anthropogenic alterations.

Keywords: benthic macrofauna, assemblages, soft bottoms, subtidal, Atlantic Ocean, Ría de Aldán.

RESUMEN: DISTRIBUCIÓN ESPACIAL DE LA MACROFAUNA BENTÓNICA DE SEDIMENTOS SUBMAREALES DE LA RÍA DE ALDÁN (GALICIA, NOROESTE DE ESPAÑA). – Durante el verano de 1997, se hicieron muestreos en 27 estaciones submareales de modo cuantitativo en la Ría de Aldán. Se recolectaron un total de 81770 individuos, pertenecientes a 496 especies. Los análisis multivariantes permitieron distinguir varias asociaciones faunísticas cuya composición puede ser referida a comunidades o facies previamente descritas de sedimentos similares: la comunidad de “*Venus fasciata*” está presente en sedimentos limpios de granulometría gruesa de la parte externa de la ría, las comunidades de “*Venus gallina*” y “*Tellina fabula-Tellina tenuis*” aparecen principalmente en arena fina en las áreas marginal y central, una fauna de transición entre las comunidades de *V. fasciata* y *V. gallina* se encuentra en fondos de arena media, y los fondos someros fangosos de la zona interna están caracterizados por una mezcla de especies propias de las comunidades de “*Syndosmya alba*” y “*Amphiura*”. En general, los sedimentos submareales de la Ría de Aldán presentaron una alta diversidad bentónica relacionada con la gran heterogeneidad sedimentaria y la ausencia de perturbaciones humanas significativas.

Palabras clave: macrofauna bentónica, asociaciones, sustratos blandos, submareal, Océano Atlántico, Ría de Aldán.

INTRODUCTION

Intertidal and shallow subtidal soft-sediment habitats constitute a small proportion of marine soft sediments (Ellis *et al*., 2000). They are, however, very productive and comprise a wide variety of habitats inhabited by a number of macrobenthic communities. Moreover, benthic faunas in coastal areas play important roles in providing food for humans, fish and birds (Ellis *et al*., 2000). In particular, macrofaunal activity influences ecosystem processes such as nutrient cycles (carbon, nitrogen and sulphur), metabolism of pollutants and transport, and dispersion and burial of sediments (Snelgrove, 1998). The composition and diversity of macrofaunal assemblages must be studied in order to determine local and regional diversity patterns (Labrune *et al*., 2008). In addition, analysis of taxonomic diversity at the species level is a prerequisite in routine monitoring studies and helps to understand the functioning of a particular community because each species is characterized by an ecological role (Maggiore and Keppel, 2007).

During the last few years, there has been an ongoing interest in the Galician rias (NW Iberian Peninsula), because they are a special and complex kind of estuarine system with high primary productivity due to upwelling and regular input of nutrients (Nombela *et al*., 1995). The Galician rias have a great economic and social importance due to the presence of fisheries, bivalve culture and shellfish resources (Nombela *et al*., 1995; Figueiras *et al*., 2002). A number of activities resulting from the growing human population concentrating on the shoreline of the rias, such as mollusc harvesting, construction of artificial structures and sewage disposal, are heavily impacting marine sedimentary environments. For example, extensive culture on rafts of the blue mussel, *Mytilus galloprovincialis* Lamarck, 1819 in the rias of southern Galicia has resulted in alterations to the benthic environment in many areas (Abella *et al*., 1996). Indeed, mussels produce large amounts of faeces and pseudofaeces which are deposited on the bottoms right beneath them (López-Jamar, 1981), often producing organic enrichment, hypoxia and changes in granulometric composition. In general, the aforementioned perturbations result in changes in the composition of benthic assemblages and impoverishment of local biodiversity (López-Jamar and Mejuto, 1988). Therefore, studying the distribution and composition of benthic assemblages in the Galician rias is paramount in order to determine the status of the sediments and the degree of perturbation when they are subjected to anthropogenic activities (López-Jamar and Mejuto, 1986).

The composition and distribution of soft-bottom benthos are well-known in many areas of the Galician coast (e.g. López-Jamar and Cal, 1990; Mora *et al.,* 1982; López-Jamar and Mejuto, 1985; Garmendia *et al.,* 1998). There is, however, a lack of studies in some small rias such as the Ría de Aldán. In fact, the ecological catastrophe which affected most of the northern coast of Spain derived from the *Prestige* oil spill (November 2002) has revealed the lack of baseline data about benthic diversity and assemblages in many areas of the Galician coast; these data are needed in order to establish the true effect of these and other disturbances on the marine environment and determine whether the biota is recovering.

The Ría de Aldán is located at the mouth of the Ría de Pontevedra and shows a variety of subtidal sediments, ranging from gravel to mud, at depths of up to 45 m. These physical features offer a good opportunity to study the patterns of distribution and composition of benthic assemblages across several sedimentary substrata at a relatively small spatial scale (<10 km). In addition, in the last years the Ría de Aldán has been subjected to bivalve culture on rafts in some areas. Therefore, the main aims of this paper are: i) to characterize the composition and distribution of the macrobenthic fauna (>0.5 mm) of the subtidal soft bottoms of the Ría de Aldán in order to provide baseline data for further comparative studies; ii) to determine the possible relation of several environmental variables to the distributional patterns of the benthic fauna; and iii) to compare the benthic biodiversity of the Ría de Aldán with that of other similar geographic areas in order to assess its ecological value. Ultimately, these data might serve to develop proper strategies for management and conservation of soft-bottom benthic habitats.

MATERIALS AND METHODS

Study area

The Ría de Aldán is located in Galicia, between 42°16’40’’ and 42°20’50’’N and 8°49’ and 8°52’W. This ria is located on the southern margin of the mouth of the Ría de Pontevedra (Fig. 1), and is 7 km long and 3.5 km wide. The Ría de Aldán has a maximum depth of 45 m, and its mouth is oriented northwards. The small Aldán River flows into the inner area, and there is an increase in salinity from the internal to the external part of the ria. The effect of this freshwater input is reduced by the strong oceanic swell and currents which reach the inner areas. Both margins of the ria are made up of rocky substratum which alternates with sandy beaches. There is a growing practice of bivalve culture on rafts in the inner parts of the ria. This activity is assumed to contribute to the increase of the content of silt/clay and organic matter in those areas, as occurs in other Galician rias.

Sample collection and processing

Quantitative sampling was done in the Ría de Aldán in July-August 1997 at 27 subtidal sites, thus covering the full extent of the subtidal domain of the ria. Samples were taken by means of a van Veen grab with a sampling area of 0.056 m^2; five replicates were taken at each site, accounting for a total area of 0.28 m^2. Samples were sieved through a 0.5 mm mesh and fixed in 10% buffered formaldehyde solution. Fixed material was later taken to the laboratory for sorting and identification of the fauna.

Granulometric composition, calcium carbonate and organic matter content was also analysed from an additional sediment sample collected at each site. The granulometric fractions were considered following the Wentworth scale (1922) and sediment types were char-

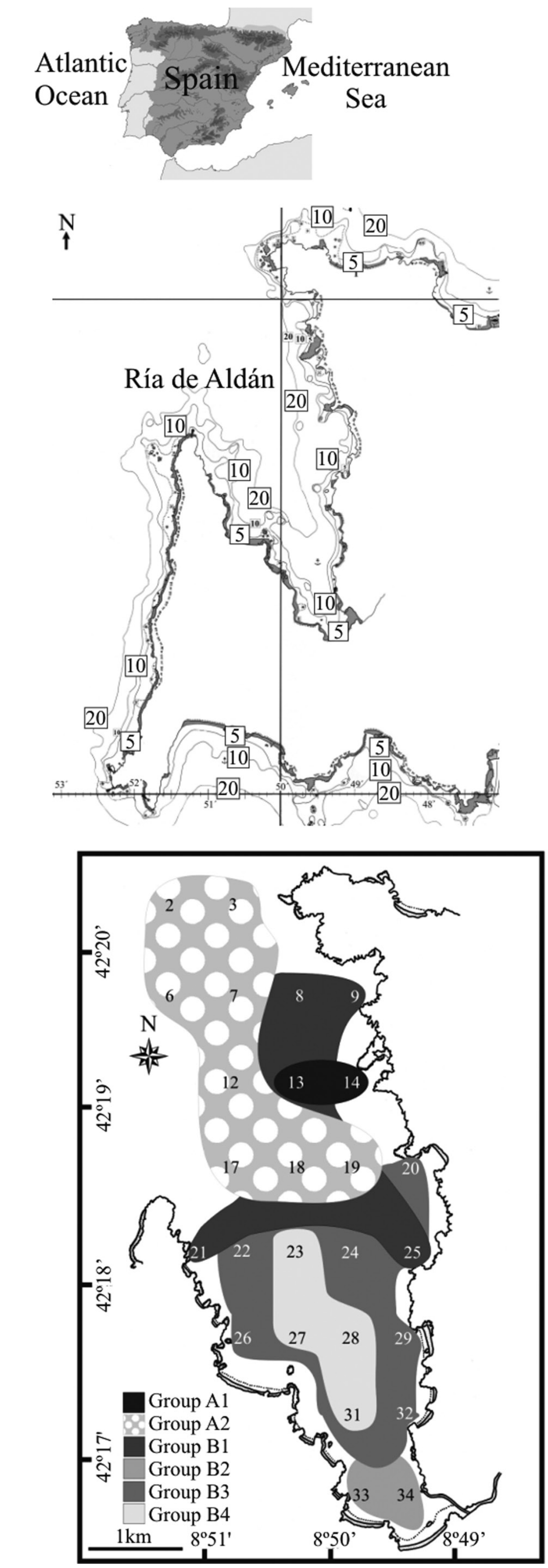

FIG. 1. – Location of the Ría de Aldán (Galicia, NW Spain), and position of the 27 sampling stations with the spatial distribution of faunal assemblages as determined by multivariate analysis.

acterized according to Junoy (1996). Moreover, median grain size (Q_{50}) and sorting coefficient (S_0) (Trask, 1932) were also determined for each sample. Temperature, Eh and pH were measured in situ in the sediment, as was the temperature of surface and bottom water. Calcium carbonate content (%) was estimated by treating the sample with hydrochloric acid, and the total organic matter content (TOM, %) was estimated from the weight loss on combustion for 4 h at 450°C (Table 1).

Data analysis

Total abundance (N), total number of species (S), the Shannon-Wiener diversity index (H', as $\log_2$) and Pielou's evenness (J') were calculated for each sampling station. At any given station, the species representing 4% or more of the total abundance were considered as numerically dominant (Field *et al*., 1982).

Faunal assemblages were determined through non-parametric multivariate techniques as described by Field *et al*. (1982) using the Plymouth Routines in the Multivariate Ecological Research software package (PRIMER; Clarke and Warwick, 1994). A similarity matrix between stations was prepared by means of the Bray-Curtis similarity coefficient after applying the fourth root transformation on the average abundance of each species (mean of five replicates) to reduce the contribution of the most abundant species. From the similarity matrix, a classification of the stations was done by cluster analysis developed from the group-average sorting algorithm and an ordination by means of non-metric multidimensional scaling (nMDS). The SIMPER program was then used to identify species that contributed highly to differentiating groups of stations determined by classification and ordination analyses. Species were classified according to the product frequency x dominance (Glémarec, 1964), which evaluates the constancy and the numerical importance of each species within a group of stations.

The potential relationship between faunal distribution in the ria and the estimated environmental variables was studied using the BIO-ENV procedure (belonging to the PRIMER package), and canonical correspondence analysis (CCA, using the CANOCO v4.02, Canonical Community Ordination package; Ter Braak, 1988). All variables expressed in percentages were previously transformed by log (x + 1), and then all of them were normalized.

RESULTS

Sediments

Sediments were chiefly sandy in most of the ria (Table 1), and their distribution followed a gradient in grain size from the mouth towards the inner areas. Muddy bottoms were confined to inner and sheltered areas, and coarser sandy granulometric fractions were more frequent at the mouth of the ria. The gravel content (0.1-52.7%) was

TABLE 1. – Depth, physico-chemical characteristics of water and sediment and main biological features of sampling stations in the Ría de Aldán.

Station	Depth (m)	Sedimentary type	Q_{50} (mm)	S_0	Carbonates (%)	TOM (%)	T (sr) (ºC)	T (bt) (ºC)	T (sed) (ºC)	pH (sed)	S	N	H' (log_2)	J'
2	45	Very coarse sand	1.08	Moderate	73.9	2.6	21.1	22.9	20	7.63	81	1012	4.85	0.76
3	36	Very coarse sand	1.98	Moderate	89.8	2.6	21.4	22.3	20.8	7.68	118	2749	3.93	0.57
6	42	Very coarse sand	1.05	Poor	32.3	1.0	18.5	18.4	18.2	7.93	122	2011	4.95	0.71
7	38	Medium sand	0.49	Moderate	67.4	1.4	17	17.7	17.4	5.75	108	2428	4.68	0.69
8	25	Fine sand	0.21	Mod. well sorted	52.7	1.3	22.1	21.4	19.6	7.7	55	977	3.23	0.56
9	12	Fine sand	0.20	Mod. well sorted	67.9	2.0	18.7	18.6	17.9	7.96	69	1099	4.11	0.67
12	33	Coarse sand	0.87	Moderate	38.2	0.7	18.1	18.6	17.2	7.75	136	1434	5.69	0.80
13	27	Medium sand	0.38	Moderate	40.8	1.1	16.8	16.7	16.6	7.69	77	1882	4.06	0.65
14	10	Medium sand	0.39	Moderate	57.0	1.3	17.3	17.4	17	7.72	59	1718	3.88	0.66
17	29	Coarse sand	0.62	Moderate	32.6	0.5	19.9	21.2	20.2	7.7	113	1006	5.55	0.81
18	25	Gravel	2.22	Moderate	33.0	2.0	18.4	18.3	17.7	7.73	153	2298	5.77	0.79
19	17	Medium sand	0.33	Moderate	64.1	1.7	18.4	18.1	17.1	7.95	108	1998	4.20	0.62
20	15	Medium sand	0.30	Moderate	55.9	2.0	18.7	18.7	17.6	7.96	115	2097	5.20	0.76
21	4	Medium sand	0.29	Moderate	70.0	3.1	21.1	20.8	20.2	7.94	68	3087	1.89	0.31
22	13	Fine sand	0.19	Mod. well sorted	55.2	1.9	21.2	21.2	20.6	7.83	101	2054	4.44	0.67
23	22	Muddy sand	0.20	Mod. well sorted	60.3	3.2	22.7	23.3	23	7.66	112	7228	3.11	0.46
24	16	Coarse sand	0.92	Moderate	65.5	2.5	20.6	21.4	21.4	7.7	119	1562	4.33	0.63
25	11	Fine sand	0.19	Mod. well sorted	54.2	1.6	21.2	21.5	21.6	7.88	82	1223	4.19	0.66
26	8	Fine sand	0.14	Moderate	59.4	2.3	21.4	21.2	21.7	7.81	121	1336	5.68	0.82
27	18	Mud	0.05	Poor	33.8	9.0	17.1	17.3	17.3	7.52	131	4789	4.35	0.62
28	19	Mud	0.05	Poor	37.8	8.8	18.7	18.2	17.6	7.36	127	3692	3.98	0.57
29	8	Fine sand	0.21	Moderate	59.9	2.2	17.9	18.2	18.2	7.71	130	2950	5.12	0.73
30	3	Coarse sand	0.87	Mod. well sorted	41.9	0.7	21.6	21.5	23.5	7.92	108	9015	2.48	0.37
31	17	Mud	0.04	Moderate	40.3	10.8	22.5	22.5	19.5	7.27	107	1965	3.73	0.55
32	12	Fine sand	0.19	Mod. well sorted	63.0	1.5	17.5	18.7	18.4	7.68	134	1935	5.22	0.74
33	4	Muddy sand	0.23	Bad	38.8	5.0	21	21.9	27.3	7.64	137	6044	4.60	0.65
34	4	Muddy sand	0.31	Poor	33.5	1.1	21.3	22.9	21.2	7.56	127	12181	4.43	0.63

Q_{50}: median grain size; S_0: sorting coefficient; TOM: total organic matter; T (sr): surface water temperature; T (bt): bottom water temperature; T (sed): sediment temperature, S: number of species; N: total abundance per 0.28 m^2; H': Shannon Wiener's diversity index; J': Pielou's evenness.

higher at stations 18 and 3 (52.7 and 47.9%, respectively), while sandy fractions (26.6-98.0%) recorded high values at stations 7, 8, 9 and 13 (96.8-98.0%). The pelitic fractions showed the highest values at inner stations 27, 28 and 31 (59.2-69.4%), whereas the rest of the stations showed lower values, from 1.4% to 13.3%. There was an increase in total organic matter content from the outer to the inner areas of the ria (0.5-10.8%), whereas the calcium carbonate values were higher than 30% at all sampling stations (32.3-89.8%). Stations 33 and 34 were also characterized by the presence of the seaweed *Ulva* spp. on the surface of the sediment.

Benthic fauna

Sampling yielded a total of 81770 specimens belonging to 496 species. Malacostracan crustaceans (162 species and 16851 individuals) and polychaetes (145 species and 28878 individuals) were the dominant groups in terms of number of species and individuals. Some taxa such as Nematoda, Nemertea and Harpacticoida were not identified to lower taxonomic levels.

Values of univariate measures are shown in Table 1. The lowest abundance values were recorded at station 8 (fine sand; 977 specimens), while the highest ones were recorded at station 34 (muddy sand; 12181 specimens). The number of species varied between 55 (St. 8) and 153 (St. 18). In general, total number of species increased towards the inner areas of the ria, showing the highest values at stations 27, 28, 29, 32, 33 and 34. The lowest number of species was recorded at the mouth of the ria, in the northeast area next to the shoreline (stations 8, 9 and 14). In number of species, polychaetes were the dominant group at 18 stations, while crustaceans dominated at 9 stations (mainly coastal stations with fine and medium sands). At station 34, polychaetes and molluscs showed a similar number of species.

In general, diversity (H') decreased from both the western and eastern margins of the mouth of the ria towards the central area. Maximum values were recorded at stations 17, 26, 12 and 18 (5.55-5.77). Minimum values were determined at stations 21, 30 and 23 (1.89-3.11); this was due either to the low number of species present or because of the high numerical dominance

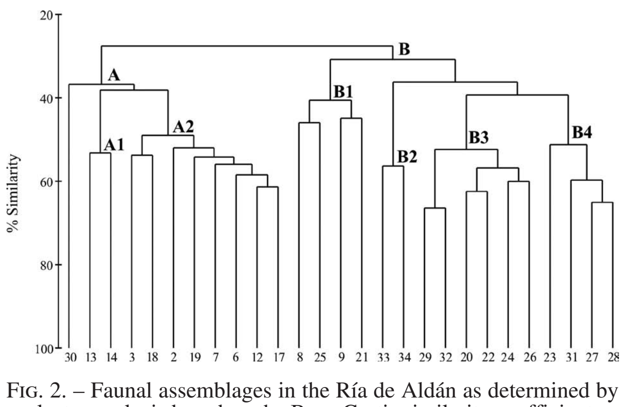

FIG. 2. – Faunal assemblages in the Ría de Aldán as determined by cluster analysis based on the Bray-Curtis similarity coefficient.

of any given species. Evenness showed low values on sediments with a high dominance of the amphipod *Siphonoecetes kroyeranus* (St. 21), nematodes (St. 30) and the polychaete *Paradoneis lyra* (St. 23 and 31).

The polychaetes *Paradoneis lyra* and *Spio decoratus*, the crustaceans Myodocopida sp. 3, *Apseudes latreillii*, *Siphonoecetes kroyeranus*, *Photis longipes* and *Gammarella fucicola*, the molluscs *Caecum trachea* and *Mysella bidentata*, and Nematoda spp. accounted for 50% of all the fauna.

The most widespread taxa in the ria, apart from the suprageneric taxa Nematoda spp., Nemertea spp. and Harpacticoida spp., were *Thracia papyracea* (found at 24 stations), *Spio decoratus*, *Heteromastus filiformis* (23

Table 2. – Summary of abiotic and biotic characteristics for each assemblage defined by multivariate analyses. TOM: total organic matter; S: number of species; N: total abundance per 0.28 m^2; H': Shannon Wiener's diversity index; J': Pielou's evenness.

		A1	A2	B1	B2	B3	B4
Q_{50} (mm)		0.38-0.39	0.33-2.22	0.19-0.29	0.23-0.31	0.14-0.92	0.04-0.2
Depth (m)		10-27	17-45	4-25	4	8-16	17-22
Carbonates (%)	Range	40.77-56.96	32.33-89.84	52.75-69.98	33.51-38.81	55.17-65.48	33.85-60.32
	Mean ± SD	48.86±11.45	53.92±22.63	61.20±8.98	36.19±3.74	59.82±3.99	43.07±11.8
TOM (%)	Range	1.12-1.33	0.47-2.60	1.25-3.08	1.08-4.97	1.47-2.50	3.17-10.8
	Mean ± SD	1.23±0.15	1.56±0.81	1.98±0.8	3.03±2.75	2.08±0.36	7.95±3.31
S	Range	59-77	81-153	55-82	127-137	101-134	107-131
	Mean ± SD	68±12.73	117.38±21.23	68.5±11.03	132±7.07	120±11.7	119.25±11.56
N	Range	1718-1882	1006-2749	977-3087	6044-12181	1336-2950	1965-7228
	Mean ± SD	1800±115.97	1867±652.04	1596.5±998.73	9112.5±4339.51	1989±556.97	4418.5±2204.39
H'(log_2)	Range	3.88-4.06	3.93-5.77	1.89-4.19	4.43-4.60	4.33-5.68	3.11-4.35
	Mean ± SD	3.97±0.13	4.950.68	3.35±1.07	4.51±0.12	5±0.52	3.79±0.52
J'	Range	0.65-0.66	0.57-0.81	0.31-0.67	0.65-0.63	0.63-0.82	0.46-0.62
	Mean ± SD	0.65±0.01	0.720.09	0.55±0.17	0.64±0.01	0.72±0.07	0.55±0.07

Table 3. – The first ten species according to frequency x dominance values of each group of stations.

	Code	A1	A2	B1	B2	B3	B4
Nematoda spp.	Nem spp	2091.25	1560.69	2062.42	963.60	557.65	597.46
Pisione parapari	Pis par	1733.70	192.91				
Spio decoratus	Spi dec	1304.99		873.18		477.99	
Streptosyllis websteri	Str web	672.11					
Thracia papyracea	Thr pap	351.84		548.41		578	
Pisione remota	Pis rem	327.98	209.04				
Nephtys cirrosa	Nep cir	197.25		204.35			
Caecum trachea	Cae tra	197.24	480.66				
Polygordius lacteus	Pol lac	189.91	391.62				
Nemertea spp.		178.91					
Protodorvillea kefersteini	Pro kef		569.17				
Goodallia triangularis	Goo tri		322.86				
Heteromastus filiformis	Het fil		298.91				
Parapionosyllis minuta	Par min		284.10				
Caulleriella bioculata	Cau bio		200.86		303.83		
Siphonoecetes kroyeranus	Sip kro			2028.08			
Pontocythere sp.	Pon sp			410.17			
Diogenes pugilator	Dio pug			290.59			
Perioculodes longimanus	Per lon			97.42		202.78	
Harpacticoida spp.	Har spp			82.75			
Nassarius reticulatus				75.36			
Myodocopida sp. 3	Myo sp3				1330.82		
Gammarella fucicola	Gam fuc				1288.56		
Photis longipes	Pho lon				506.21	549.40	
Pholoe synophthalmica					287.47		
Parvicardium exiguum					284.42		
Syllis garciai	Syl gar				217.94		
Mysella bidentata	Mys bid				165.95	292.27	884.87
Ampithoe ramondi					143.10		
Apseudes latreillii	Aps lat					1345.68	
Paradoneis armata	Par arm					443.73	
Chaetozone gibber	Cha gib					224.37	
Chamelea striatula	Cha str					211.46	
Paradoneis lyra	Par lyr						4003.67
Prionospio pulchra	Pri pul						607.14
Thyasira flexuosa	Thy fle						455.84
Abra alba	Abr alb						246.22
Ampharete finmarchica							217.26
Amphiura chiajei							140.24
Euclymene oerstedii							130.35
Exogone hebes							120.85

stations each), and *Nephtys cirrosa*, *Leucothoe incisa*, *Tellina donacina* and *Dosinia exoleta* (22 stations each).

Multivariate analysis

The dendrogram obtained by cluster analysis showed the presence of two major groups of stations at a similarity level of 30% (Fig. 2). Group A was further subdivided into group A1 (medium-sand) and group A2 (coarse sand) at a similarity level of 40%. Group B was subdivided into B1 (fine-sand stations close to the shoreline), B2 (muddy sand), B3 (fine sand) and B4 (mud) at a similarity level of 40%. nMDS ordination showed similar results to those of the dendrogram (stress: 0.13). The summary of characteristics for each association is shown in Table 2 and the first ten species according to frequency x dominance values of each group of stations are shown in Table 3.

Group A was located in the outer part of the ria. The species which mostly contributed to characterizing group A1 (medium sand) were *Spio decoratus*, *Pisione parapari*, *Streptosyllis websteri*, *Pisione remota*, *Nephtys cirrosa*, *Caecum trachea*, *Polygordius lacteus*, *Thracia papyracea* and Nemertea spp. Group A2 (coarse sand) was characterized by several polychaete species, such as *Polygordius lacteus*, *Pisione parapari*, *Pisione remota*, *Parapionosyllis minuta*, *Heteromastus filiformis*, *Caulleriella bioculata* and *Protodorvillea*

Table 4. – Results of SIMPER analysis. Species were ranked according to their average contributions to dissimilarity (AD) between assemblages in the Ría de Aldán. Average abundance (AA), ratio value (R: dissimilarity/standard deviation) and percentage of cumulative dissimilarity (%Cum) were also included.

	AA	AA	AD	R	%Cum
Groups A1-A2					
(average dissimilarity: 61.83)	A1	A2			
Protodorvillea kefersteini	-	102.75	0.91	2.11	1.47
Streptosyllis websteri	120	4.88	0.89	3.1	2.91
Spio decoratus	234	23.5	0.88	2.04	4.34
Pisione parapari	307	36.25	0.68	2.1	5.45
Syllis sp. 1	-	21.63	0.68	2.27	6.55
Syllis pontxioi	-	15.63	0.66	3.6	7.62
Sphaerosyllis bulbosa	-	33	0.66	2.97	8.69
Chaetozone gibber	-	32.13	0.66	1.8	9.75
Heteromastus filiformis	1	63.38	0.64	1.79	10.79
Groups A1-B1					
(average dissimilarity: 64.09)	A1	B1			
Pisione parapari	307	-	1.87	5.98	2.91
Pontocythere sp.	-	49	1.25	5.54	4.87
Pisione remota	57	-	1.16	3.18	6.69
Polygordius lacteus	34.5	-	1.08	12.51	8.37
Siphonoecetes kroyeranus	36.5	608.25	1.02	1.23	9.96
Hesionura elongata	24	-	0.97	10.13	11.47
Groups A2-B1					
(average dissimilarity: 76.89)	A2	B1			
Siphonoecetes kroyeranus	0.25	608.25	1.04	1.54	1.36
Polygordius lacteus	66.75	-	0.97	5.72	2.62
Pontocythere sp.	0.13	49	0.93	4.05	3.83
Protodorvillea kefersteini	102.75	-	0.91	2.13	5.01
Parapionosyllis minuta	46.5	-	0.83	3.36	6.09
Pisione remota	37	-	0.81	3.23	7.15
Syllis garciai	29.75	-	0.8	5.45	8.19
Caulleriella bioculata	30	-	0.78	3.76	9.2
Paradoneis lyra	26.38	-	0.74	4.45	10.16
Groups A2-B3	A2	B3			
Apseudes latreillii	25.88	241.5	0.75	1.65	1.1
Polygordius lacteus	66.75	0.17	0.73	4.53	2.16
Parapionosyllis minuta	46.5	0.17	0.61	2.81	3.07
Photis longipes	0.88	139	0.61	2.19	3.97
Protodorvillea kefersteini	102.75	3.83	0.61	1.71	4.85
Goodallia triangularis	68.25	2.67	0.6	1.83	5.74
Pisione remota	37	0.17	0.6	2.81	6.61
Perioculodes longimanus	-	38.67	0.59	3.33	7.48
Paradoneis armata	0.75	85.33	0.59	1.73	8.34
Pisione parapari	36.25	0.17	0.55	2.09	9.15
Syllis garciai	29.75	2.17	0.55	2.47	9.96
Syllis sp. 1	21.63	-	0.54	2.33	10.76

	AA	AA	AD	R	%Cum
Groups A2-B4					
(average dissimilarity: 74.75)	A2	B4			
Prionospio pulchra	-	308.25	0.91	4.34	1.21
Paradoneis lyra	26.38	1737.75	0.88	4.37	2.39
Polygordius lacteus	66.75	-	0.83	6.07	3.51
Thyasira flexuosa	-	195.75	0.79	3.76	4.56
Caecum trachea	88.25	-	0.73	2.35	5.54
Goodallia triangularis	68.25	-	0.72	2.08	6.51
Parapionosyllis minuta	46.5	-	0.71	3.4	7.46
Protodorvillea kefersteini	102.75	0.5	0.7	1.84	8.4
Pisione remota	37	-	0.69	3.36	9.32
Caulleriella bioculata	30	-	0.67	3.83	10.21
Groups B1-B3					
(average dissimilarity: 60.71)	B1	B3			
Apseudes latreillii	3	241.5	0.76	1.47	1.26
Caulleriella alata	-	30	0.75	6.24	2.5
Chaetozone gibber	-	51.33	0.71	1.78	3.67
Ampelisca typica	-	21.33	0.69	4.85	4.8
Photis longipes	3.5	139	0.67	1.94	5.91
Mysella bidentata	3.75	62.33	0.63	1.97	6.95
Siphonoecetes kroyeranus	608.25	15	0.6	0.89	7.94
Diogenes pugilator	34.75	14	0.59	1.74	8.91
Parvicardium scabrum	-	14	0.57	3.79	9.85
Chamelea striatula	3.5	42.33	0.55	1.7	10.76
Groups B3-B2					
(average dissimilarity: 61.52)	B2	B3			
Myodocopida sp. 3	1616.5	0.33	0.79	1.49	1.28
Gammarella fucicola	804.5	3.5	0.76	1.72	2.51
Parvicardium exiguum	250.5	-	0.74	22.14	3.72
Paradoneis armata	-	85.33	0.7	2.12	4.86
Apseudes latreillii	745	241.5	0.64	1.59	5.9
Caulleriella alata	-	30	0.62	6.82	6.91
Syllis garciai	234	2.17	0.59	2.39	7.86
Chaetozone gibber	-	51.33	0.59	1.75	8.81
Ampelisca typica	-	21.33	0.57	4.85	9.73
Amphipholis squamata	105	0.17	0.56	5.11	10.65
Groups B3-B4					
(average dissimilarity: 61.36)	B3	B4			
Paradoneis lyra	6	1737.75	1.11	4.36	1.81
Apseudes latreillii	241.5	1	0.9	2.15	3.28
Thracia papyracea	117.5	5	0.73	3.46	4.46
Prionospio pulchra	2.17	308.25	0.64	2.45	5.51
Thyasira flexuosa	1.17	195.75	0.64	2.28	6.56
Paradoneis armata	85.33	51.5	0.61	1.72	7.55
Photis longipes	139	2.75	0.6	1.86	8.53
Spio decoratus	92.5	9.75	0.55	2.21	9.43
Myodocopida sp. 4	-	43	0.55	3.7	10.33

kefersteini, and the molluscs *Caecum trachea* and *Goodallia triangularis*. Group B was located in the sheltered area of the ria. The species that most contributed to similarities in B1 were *Pontocythere* sp., *Nephtys cirrosa, Siphonoecetes kroyeranus*, *Thracia papyracea*, *Spio decoratus*, *Diogenes pugilator*, *Perioculodes longimanus*, Harpacticoida spp. and *Nassarius reticulatus*. Group B2 (muddy sand) was characterized by *Caulleriella bioculata*, *Syllis garciai*, Myodocopida sp. 3, *Gammarella fucicola*, *Photis longipes*, *Pholoe synophthalmica*, *Parvicardium exiguum*, *Mysella bidentata* and *Ampithoe ramondi*, while Group B3 (fine sand) was characterized by *Thracia papyracea*, *Spio decoratus*, *Apseudes latreillii*, *Mysella bidentata*, *Photis longipes*, *Perioculodes longimanus*, *Paradoneis armata*, *Chaetozone gibber* and *Chamelea striatula*. The species which most contributed to characterizing group B4 (mud) were *Paradoneis lyra*, *Mysella bidentata*, *Prionospio pulchra*, *Ampharete finmarchica*, *Abra alba*, *Amphiura chiajei*, *Euclymene oerstedii*, *Exogone hebes* and *Thyasira flexuosa*.

SIMPER analysis (Table 4) showed that *Protodorvillea kefersteini*, *Streptosyllis websteri*, *Spio decoratus* and *Pisione parapari* explained most of the dissimilarity between groups A1 and A2. *Pisione parapari*, *Pontocythere* sp. and *Pisione remota* contributed greatly to the differentiation of A1 from B1. *Siphonoecetes kroyeranus* and *Polygordius lacteus* differentiated group A2 from B1. Group A2 differed from B3 due to *Apseudes latreillii* and *Polygordius lacteus*. *Prionospio pulchra* and *Paradoneis lyra* differentiated group A2 from B4, whereas *Apseudes latreillii* and *Caulleriella alata* differentiated group B1 from B3. Myodocopida sp. 3, *Gammarella fucicola* and *Parvicardium exiguum* explained most of the dissimilarity between groups B2 and B3, while *Paradoneis lyra* and *Apseudes latreillii* greatly contributed to separating B3 from B4.

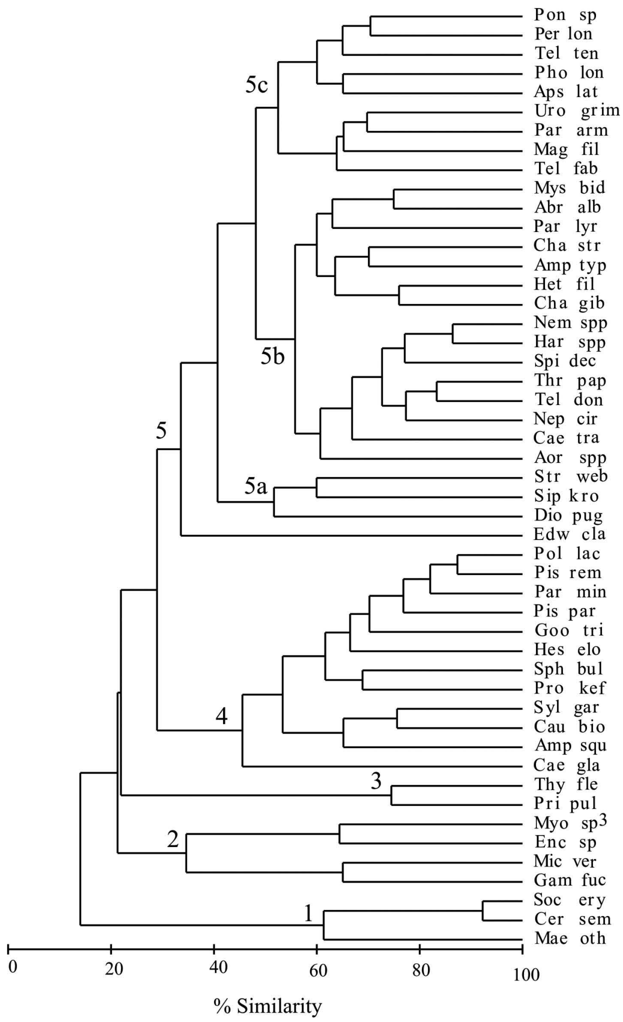

FIG. 3. – Dendrogram based on cluster analysis showing the classification of species with a numerical dominance ≥4% at any given site. Species codes are given in Table 3, except: *Ampelisca typica*: Amp typ; *Amphipholis squamata*: Amp squ; Aoridae spp: Aor spp; *Caecum glabrum*: Cae gla; *Ceradocus semiserratus*: Cer sem; *Edwarsia claparedii*: Edw cla; Enchytraeida sp.: Enc sp; *Maera othonis*: Mae oth; *Magelona filiformis*: Mag fil; *Microdeutopus versiculatus*: Mic ver; *Socarnes erythrophthalmus*: Soc ery; *Sphaerosyllis bulbosa*: Sph bul; *Tellina donacina*: Tel don; *Tellina fabula*: Tel fab; *Tellina tenuis*: Tel ten; *Urothoe grimaldii*: Uro grim.

Species affinities

Cluster analysis done on the abundance data of the dominant species showed the existence of five major groups at the similarity level of 30% (Fig. 3). Group 1 comprised species mostly found in gravel, group 2 comprised species found in muddy sands (cluster group B2), while group 3 comprised species with higher abundance in mud (cluster group B4). Group 4 was composed of nine species mostly found in coarse sand (cluster group A), and three species mostly found in muddy sand. Finally, group 5 was subdivided into group 5a (fine-sand species), 5b (a number species found in several types of sediment) and 5c (species found in fine and muddy sands).

Relation of benthic fauna with environmental variables

The BIO-ENV procedure showed that the combination of gravel, coarse sand, fine sand, very fine sand, depth, redox potential (Eh) and total organic matter content had the highest correlation with faunistic data (ρ_w: 0.615). Very fine sand was the variable that alone showed the highest correlation with the faunistic data (ρ_w: 0.462).

Axes I and II of the forward selection of CCA were the most important in the CCA ordination, accumulating 24.1% of species variance and 31.1% of species-environment variance. Cluster groups with higher content of coarser granulometric fractions were distributed on the left of the ordination, while assemblages distributed along fine-sand and muddy sediments were distributed on the right, following a gradient defined by a decrease in median grain size (Fig. 4).

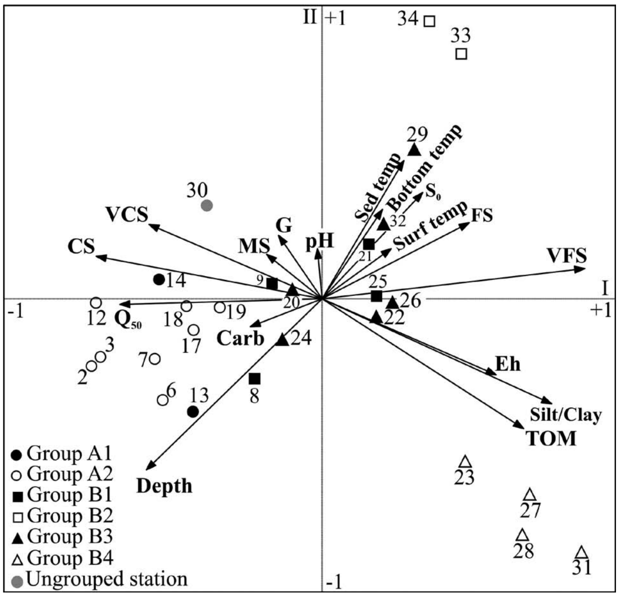

FIG. 4. – Canonical correspondence analysis (CCA) ordination of stations and environmental variables relative to axes I and II for the Ría de Aldán. Gravel, G; very coarse sand, VCS; coarse sand, CS; medium sand, MS; fine sand, FS; very fine sand, VFS; median grain size, Q_{50}; sorting coefficient, S_0; bottom temperature, Bottom temp; sea surface temperature, Surf temp; sediment temperature, Sed temp; carbonate content, Carb; total organic matter content, TOM.

DISCUSSION

This study shows that the Ría de Aldán has a diverse soft-bottom benthic fauna. In total, 496 different taxa were found in a variety of sediments ranging from very coarse sand to mud. The multivariate analyses revealed the presence of several benthic assemblages whose distribution along the ria is related to that of sediment types. In addition, the faunistic composition of the assemblages mostly agrees with those of several communities or facies, as described by Petersen (1918) or Thorson (1957). Thus, the assemblage of group A2 of cluster can be included among the different varieties of the *Branchiostoma lanceolatum-Venus fasciata* community (Thorson, 1957) present on clean coarse sediments with a high content of biogenic carbonates (Table 5). The medium-sand assemblage corresponding to group A1 showed intermediate features between the *Venus fasciata* community and the *Venus gallina* community (fine sand); this group has a low number of exclusive species (3), suggesting that these sites are a transition zone between different assemblages, i.e. the coarse-sand assemblage (group A2) and the fine-muddy sand assemblage (group B). The fine-sand sites of group B1 are characterized by species which are typical of the *Venus gallina* community (Thorson, 1957). The muddy sands of group B2 are located in the inner ria, into which the Aldán River flows; this group is characterized by the presence of seaweeds (*Ulva* spp.) that may favour the appearance of epifaunal species such as *Bittium reticulatum*. Group B3 (the fine-sand assemblage) shows similarities with the *Venus gallina* community described by Thorson (1957); coastal and shallow sites also have typical species from the *Tellina tenuis-Tellina fabula* community (Thorson, 1957). Group B4 is characterized by muddy sediments showing the highest content of organic matter in the ria. The species found there are characteristic of the *Syndosmya alba* community and the *Amphiura* community. In general, the distribution of assemblages and sediments is similar to that found in other Galician rias with similar orientation and exposure to oceanic swell such as the Ría da Coruña (López-Jamar and Mejuto, 1985), the Ría de Ares-Betanzos (Garmendia *et al*., 1998) and the Ensenada de Baiona (Moreira and Troncoso, 2008).

Soft bottom faunas are often structured by abiotic factors (Labrune *et al*., 2008). Several studies have highlighted sedimentary features among the most important factors influencing the composition and distribution of benthic assemblages in marine sediments (e.g. Pearson and Rosenberg, 1978). In the Ría de Aldán, there is a correlation between the spatial distribution of the benthic fauna and the granulometric composition of the sediment. Thus, there is a conspicuous grain-size gradient in the study area, which is defined by an increase in finer sandy fractions from the mouth of the ria towards the inner margins. When studied separately, the distribution of the molluscan, polychaete and peracarid assemblages in the Ría de Aldán also follows this sedimentary gradient (Lourido *et al*., 2006, 2008a,b). Although hydrodynamic features of the Ría de Aldán were not measured, hydrodynamism is known to act as a “superparameter” which has a major influence on sedimentation of particles and organic matter, stability of sediments and patterns of sedimentary distribution, and therefore on faunal composition (Rosenberg, 1995). In general, the particular overall granulometric composition of the sediments in the Galician rias is a consequence of the hydrodynamic regime found there (López-Jamar, 1981). Thus, the greater hydrodynamism due to exposure to oceanic swell in the outer areas of the rias does not allow deposition of finer particles and results in the presence of coarser sediments (Troncoso *et al*., 1993); finer sediments occurs in sheltered, inner areas of low energy. The effects of hydrodynamism thus result in a gradation of sediment grain size along the rias, which translates into a presence of assemblages typical of coarse sediment in the outer areas and those of fine sand or mud in the inner areas. Those patterns can be altered by the construction of artificial structures on the shoreline, which results in changes in current dynamics (López-Jamar and Mejuto, 1985), or by the deposition on the sediment of large amounts of pseudofaeces produced by mussels cultured on rafts (Abella *et al*., 1996).

The total number of species has been used to describe biodiversity in many studies (Olsgard *et al*., 2003) and therefore will be used here as a simple measure to establish comparisons in benthic diversity among different areas. In general, the total number of species found on the subtidal soft bottoms of the Ría

Table 5. – Characteristic species of the benthic assemblages of the Ría de Aldán determined by multivariate analyses; other assemblages in which those species were previously reported are also indicated. 1, *Venus fasciata* community (Glémarec, 1973); 2, Assemblage of *Goniadella-Spisula* (Salzwedel *et al*., 1985); 3, *Branchiostoma lanceolatum* of gravel and sandy gravel facies (Toulemont, 1972); 4, Gravel and coarse sand assemblage (Troncoso and Urgorri, 1993); 5, Coarse-sand sediments (Besteiro *et al*., 1987); 6, Facies of *Zostera noltii* (Olabarria *et al*., 1998); 7, *Syndosmya alba* community (Petersen, 1918); 8, Other facies from *Syndosmya alba* community; 9, Heterogeneous sandy gravels and heterogeneous muddy sands (Chassé and Glémarec, 1976); 10, Boreo-mediterranean *Amphiura* community (Petersen, 1918); 11, *Maldane glebifex-Amphiura filiformis-Amphiura chiajei* subcommunity (Toulemont, 1972); 12, Mud assemblage (Moreira *et al*., 2006).

Species	Characteristic species	Facies/ Community	Species	Characteristic species	Facies/ Community
Goodallia triangularis	A1	4	Myodocopida sp. 3	B2	
Pisione remota	A1	2	*Gammarella fucicola*	B2	
Streptosyllis websteri	A1		*Parvicardium exiguum*	B2	
Spio decoratus	A1		*Apseudes latreillii*	B2, B3	
Pisione parapari	A1		*Photis longipes*	B2, B3	
Lepidepecreum longicornis	A1		*Mysella bidentata*	B2, B4	
Atylus falcatus	A1		*Spisula elliptica*	B3	
Gastrosaccus spinifer	A1	1	*Tellina fabula*	B3	
Nephtys cirrosa	A1, A2, B1, B3	1, 2	*Echinocardium cordatum*	B3	
Caecum trachea	A1, A2, B2	4	*Tellina tenuis*	B3	
Thracia papyracea	A1, B1, B3		*Magelona filiformis*	B3	
Protodorvillea kefersteini	A2	5	*Chamelea striatula*	B3	
Polygordius lacteus	A2	1, 3, 5	*Abra alba*	B4	7, 8, 9, 11
Caecum glabrum	A2		*Corbula gibba*	B4	7, 9
Branchiostoma lanceolatum	A2	1	*Lagis koreni*	B4	7, 8, 11
Echinocyamus pusillus	A2	1	*Nucula nitidosa*	B4	7, 10
Clausinella fasciata	A2	4	*Abra nitida*	B4	8, 10, 11
Gari tellinella	A2	1, 3	*Euclymene oerstedii*	B4	8
Arcopagia crassa	A2	1, 4	*Melinna palmata*	B4	8, 11
Ampelisca spinipes	A2	3	*Pherusa eruca*	B4	9
Glycera lapidum	A2	3, 4	*Terebellides stroemi*	B4	9, 10, 11
Timoclea ovata	A2	3	*Thyone fusus*	B4	9
Digitaria digitaria	A2	4	*Turritella communis*	B4	9
Tellina donacina	A2	4	*Amphiura chiajei*	B4	10
Retusa mammillata	A2	4	*Aporrhais pespelecan*	B4	10
Microjaera anisopoda	A2	5	*Myrtea spinifera*	B4	11
Siphonoecetes kroyeranus	B1		*Cossura pygodactylata*	B4	12
Nassarius reticulatus	B1		*Podarkeopsis capensis*	B4	12
Perioculodes longimanus	B1, B3		*Exogone hebes*	B4	12
Venerupis senegalensis	B2	6	*Prionospio fallax*	B4	12
Bittium reticulatum	B2	6	*Paradoneis lyra*	B4	
Loripes lacteus	B2	6	*Prionospio pulchra*	B4	
Lucinoma borealis	B2		*Thyasira flexuosa*	B4	8, 10

de Aldán (496) was high taking into account the spatial scale of sampling (<10 km) and in comparison with other Galician rias and with estuaries, fjords and bays across the European Atlantic (see Table 6). However, accurate comparisons among different geographic areas according to total number of species and other biological parameters are limited by differences in local physical conditions, taxonomic knowledge, sampling procedures (e.g. mesh size, sampling gear, sample size) and time of the year of sampling (De Grave *et al*., 2001). The benthic biodiversity of the Ría de Aldán mostly agrees with that reported from other similar Galician rias, such as the Ría de Ares-Betanzos and the Ensenada de Baiona. This high biodiversity might be related to the variety of sediments present in these rias, ranging from gravel to mud. In short, this sedimentary heterogeneity provides a large variety of ecological niches across a small spatial scale, thus supporting a greater diversity of species than more homogenous sediments do (Pearson and Rosenberg, 1978). In addition, the high primary production related to upwelling events occurring in the rias usually twice a year (Figueiras *et al*., 2002) might grant a priori an important food supply for the benthic fauna which, in turn, might benefit the presence of richer faunas there than in other areas. On the contrary, previous work done in other Galician rias of similar or greater size (e.g. Ría de Vigo, Ría de Pontevedra) shows that these have a smaller number of species (Mora *et al*., 1982; López-Jamar and Cal, 1990). This fact might be related to the greater sedimentary homogeneity found there, with a predominance of the silt/clay fractions; the greater presence of mud is greatly related to anthropogenic alterations such as those reported above.

In conclusion, the subtidal sediments of the Ría de Aldán show a rich benthic fauna whose diversity and distribution is linked to the hydrodynamic and sedimentary features, as occurs in other Galician rias. The overall situation suggests that most of the benthic environment of the Ría de Aldán has not yet been greatly altered by phenomena of organic enrichment in spite of the presence of a number of rafts devoted to mussel culture in the central part of the ria. Nevertheless, our results emphasize, again, the need for baseline studies to obtain a basic knowledge of the environment in order to develop proper short- and long-term strategies for conservation that will avoid impoverishment of benthic assemblages and loss of biodiversity.

Table 6. – Comparison of total number of species (N) of macrobenthic fauna in the Ría de Aldán and that in other European areas. Main physical features of sampling areas and sampling methodology are also indicated for bibliographic references.

Geographic area	N	Spatial scale (km)	Depth (range, m)	Substrata (range)	Sampling stations	Mesh size (mm)	Sampling gear
Galicia (NW Spain)							
Ría de Aldán (this work)	496	<10	3-45	VCS-M	27	0.5	VV
Ensenada de Baiona (Moreira and Troncoso, 2008)	474	<10	2-12	GR-M	21	0.5	VV
Ensenada de San Simón (Cacabelos *et al*., 2008)	362	<10	1-28	VCS-M	29	0.5	VV
Ría de Vigo (López-Jamar and Cal, 1990)	137	25	10-35	S-M	21	0.5	BC
Ría de Pontevedra (Mora *et al*., 1982)	229	20	0-40	CS-M	32	N/A	VV, RB
Ría de Arousa (López-Jamar, 1982)	110	15	10-40	S-M	13	0.5	VV
Ría de Muros (López-Jamar, 1981)	109	10	15-45	S-M	13	0.5	VV
Ría de Coruña (López-Jamar and Mejuto, 1985)	129	<10	8-33	CS-M	26	0.5	BC
Ría de Ares-Betanzos (Garmendia *et al*., 1998)	426	12	2-44	GR-SM	53	1.0, 0.5	BC, RB
Iberian Peninsula (excluding Galicia)							
Bahía de Santander (Lastra *et al*., 1990)	197	<10	0-21	MS-M	45	1.0	VV
Sado Estuary (Carvalho *et al*., 2001)	151	<10	5-20	CS-M	31	1.0	SM
Albufeira Lagoon (Quintino *et al.*, 1987)	126	<10	0-15	CS-M	50	1.0	PO, RB
European Atlantic					31		
Oslofjord, Norway (Mirza and Gray, 1981)	146	35	0-160	M	76	1.0	TD
Olderfjord, Lafjord, Byluft Bay (Holte *et al*., 2004)	399	<10	10-90	S-M	13	1.0	VV
Arcachon Bay (Bachelet *et al*., 1996)	141	20	2-18	GR-M	18	1.0	SM, SH, EK
Marennes-Oléron Bay (Montaudouin and Sauriau, 2000)	332	25	0-15	N/A	262	1.0	SM, manual corers
Mediterranean							
Mar Grande, Mar Piccolo (Mastrototaro *et al*., 2008)	131	10	5-35	SM-M	47	N/A	VV
Argolikos Bay (Makra and Nicolaidou, 2000)	151	<10 km	5-10	S-M	7	1.0	PO

GR, gravel; VCS, very coarse sand; CS, coarse sand; MS, medium sand; S, sand; SM, sandy mud; M, mud. BC, Box Corer; EK, Ekman grab; PO, Ponar grab; Rallier du Baty. SH, Shipek grab; SM, Smith-McIntyre grab; TD, Triangular dredge; VV, Van Veen grab.

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