INTERTIDAL MACROBENTHIC COMMUNITIES STRUCTURE IN THE MONDEGO ESTUARY (WESTERN PORTUGAL) : REFERENCE SITUATION

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COMMUNAUTÉS ESTUARIENNES
MACROBENTHOS
SITUATION DE RÉFÉRENCE

RÉSUMÉ – L'estuaire du Mondego, divisé en deux bras, nord et sud, hydrologiquement très différents, subit un stress environnemental sévère. Une étude des communautés intertidales a été effectuée en décembre 1986 et juillet 1987, pour caractériser une situation de référence et servir de base à des travaux ultérieurs sur l'impact des activités humaines. L'analyse structurale des communautés a mis en évidence des différences entre les deux bras de l'estuaire, notamment en ce qui concerne la densité des populations et la biodiversité, ce qui est en accord avec l'analyse des facteurs physiques et chimiques. Le bras sud semble moins perturbé, présentant des conditions plus favorables au développement de populations abondantes d'espèces typiquement estuariennes. La salinité semble être le premier facteur qui conditionne la répartition des organismes sur substrats durs, tandis que la granulométrie et le pourcentage de matière organique, la salinité et l'oxygène dissous dans l'eau sont les plus importants pour les organismes de substrats meubles. Les aires à *Spartina maritima* et à *Zostera noltii*, surtout localisées au milieu du bras sud, sont les plus riches, présentant des populations plus denses et une biodiversité plus élevée. Des travaux ultérieurs seront nécessaires pour suivre les tendances évolutives des communautés macrobenthiques.

ESTUARINE COMMUNITIES
MACROBENTHOS
REFERENCE SITUATION

ABSTRACT – The Mondego estuary, consisting of two arms, north and south, with very different hydrographic characteristics, is under severe environmental stress. In December 1986 and July 1987, a study was carried out over the intertidal communities in order to provide reference data on which further studies on the impact of human activities could be based. The analysis of the communities structure revealed differences between the two estuarine arms for populations densities and biodiversity, which is consistent with results from the analysis of physicochemical data. The southern arm appears to be less affected by human activities, presenting more favourable conditions for the development of abundant populations of typical estuarine species. Salinity appears to be the most important factor controlling the distribution of hard substrates organisms, while granulometry and organic matter contents of sediments, salinity, and dissolved oxygen in the water column are the most important factors for soft substrates organisms. *Spartina maritima* and *Zostera noltii* marshes, mainly located in the middle section of the southern arm, present the richest macrofaunal composition with regard to both abundance and biodiversity. Further work will be necessary in order to monitor changes and to understand the evolutive trends of macrobenthic communities.

INTRODUCTION

The Mondego river drains a hydrological basin of nearly 6670 km^2 and its estuary (Fig. 1) is the location of Figueira da Foz, a commercial harbour of regional vital importance. Besides the harbour facilities and dredging activities, causing physical disturbance of the bottoms, the Mondego estuary supports industrial activities, many salt-works, and aquaculture farms. It also receives the nutrient and chemical discharge from agricultural areas in the river valley, which can be especially significant in rainy periods. All these factors contributed to a severe increase of environmental stress.

Despite the increasing pressure, until 1985 there was no reference data on the Mondego estuary on which further studies on the impact of human activities over the structure and functioning of the ecosystem could be based.

From 1985 to 1990 a reference study on the benthic communities was carried out, regarding both the intertidal and subtidal zones. The aims of the study were :

a) To characterize the macrobenthic communities structure in relation to physicochemical environmental factors;

b) To identify the most important species, which could play a key role in the ecosystem functioning.

Results regarding the characterization of the intertidal communities are presented in this paper.

MATERIAL AND METHODS

Study site

The Mondego estuary is located in a warm-temperate climate. It consists of two arms, north and south (Fig. 1), with very different hydrographic characteristics. The northern arm, where the harbour is located, is deeper and the freshwater flows essentially by the northern arm, while the southern arm is almost silted up in the upstream section. Consequently, the water circulation in the southern arm is mostly due to tides and to the usually small freshwater input of the Pranto river (Fig. 1). In addition, due to differences in depth, the tidal penetration tends to be faster along the northern arm causing stronger daily salinity changes, while daily temperature changes are more significant in the southern arm (Marques, 1989).

In both estuarine arms hard substrates are covered primarily by *Enteromorpha* and *Fucus* species, which form eulittoral macroalgae belts. Near the mouth of the estuary *Fucus spp.* appear clearly mixed with marine elements (e.g. *Chthamalus stellatus* and *Mytilus galloprovincialis*), and *Ulva sp.* shows a significant development in the upper limits of the sublittoral zone. Hard substrates result essentially from human occupation (e.g. harbour facilities, aquaculture farms, salt works), corresponding to about half of the estuarine perimeter. An important area of the intertidal zone, especially along the southern arm of the estuary, is still unchanged, presenting sediments from sand to mud, and in these areas *Spartina maritima* and *Zostera noltii* can cover a significant part of the eulittoral zone. Uncommon macroalgae blooms of *Enteromorpha spp.* have been observed in the southern arm, probably as the result of excessive nutrients release from the river valley into the estuary.

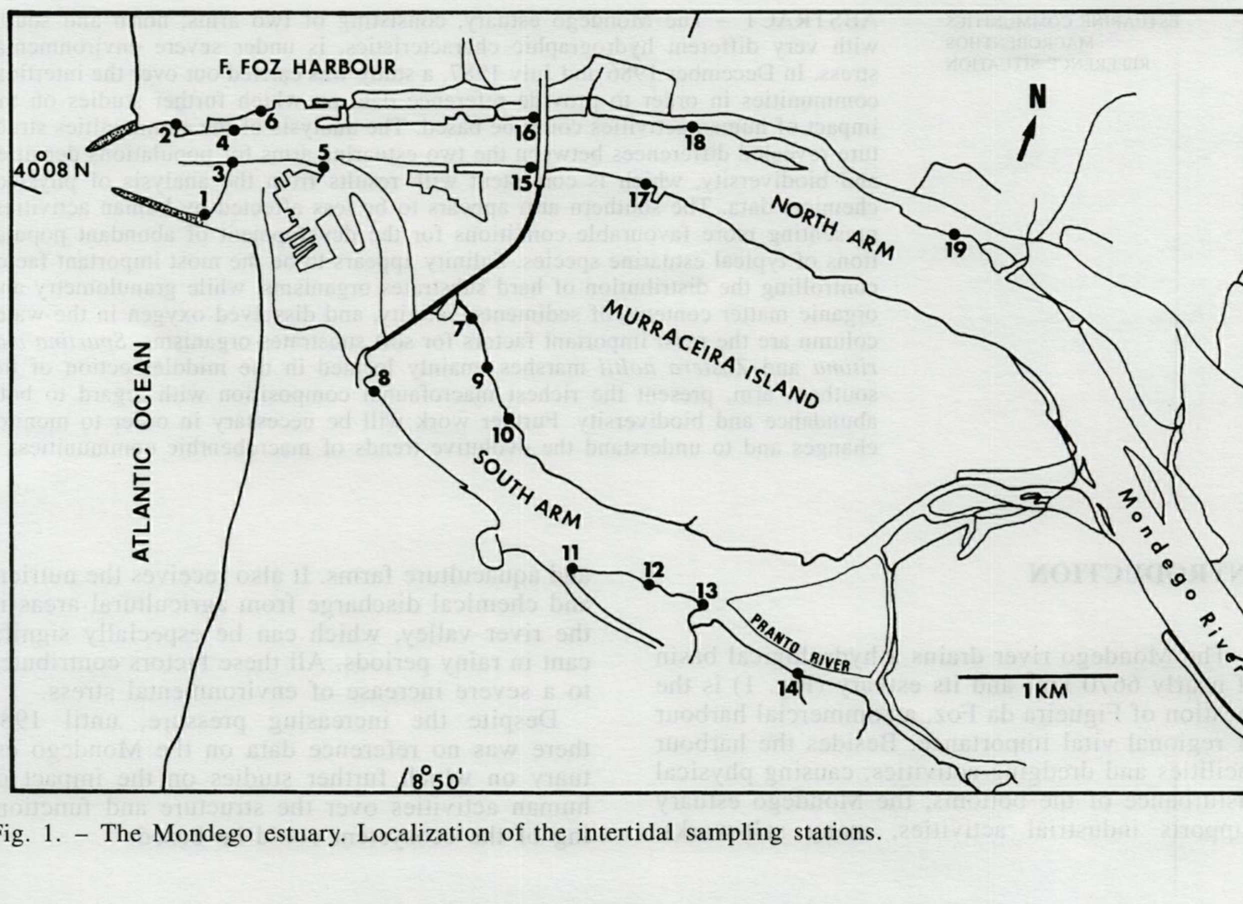

Fig. 1. – The Mondego estuary. Localization of the intertidal sampling stations.

Field program

In December 1986 and July 1987 quantitative samples were carried out in 19 sampling stations (Fig. 1), in order to characterize the communities structure in winter and summer situations. Each time, sampling took place in five consecutive days, always in the morning and during a 3 hours period in low water. This allowed samples to be carried out in approximately uniform conditions.

Both hard and soft substrates were frequently found in the same sampling station, and depending on the intertidal slope the sampling area was quite variable. On soft substrates, *Spartina maritima* and *Zostera noltii marshes* could be present or not, depending on the sampling station.

In order to establish an uniform sampling criterion, in each station the intertidal zone was stratified, taking into consideration different eulittoral levels, and the type of macroalgae or macrophytes covered areas. This criterion allowed to consider three approximately equidistant levels between high water and low water levels. On hard substrates, depending on the sampling site, the two upper levels corresponded approximately to *Enteromorpha spp.* and *Fucus spp.* algal belts, whereas the lower level in stations located near the mouth of the estuary presented also a significant population of *Mytilus galloprovincialis* (mussels). On soft substrates with vegetal covered areas the two upper levels frequently corresponded respectively to the marsh-grass *Spartina maritima* belt and to the eel-grass *Zostera noltii* meadows, while the lower level corresponded mainly to sandy or muddy substrates without macrophytes.

Two different sampling techniques were used as a function of the type of substrate. On hard substrates three replicates of 625 cm^2 were randomly sampled in each level by scratching out organisms with a chisel. On soft substrates we adapted the technique described by Dexter (1979; 1983) for sandy beaches, and eight replicates were randomly sampled in each level by using a manual corer, each core corresponding to 141 cm^2 and approximately 3 liters of sediment.

All the biological samples were sieved *in situ* using a 1 mm mesh size sieve, and then fixed in 4 % neutralized formol. This mesh size was considered suitable for this study, regarding the types of sediment we expected to find along the estuary.

Each time and for each station, several physicochemical factors were determined, respectively salinity, temperature, pH, dissolved oxygen (measured *in situ*), nitrites, nitrates, and phosphates (analysed in the laboratory). The analysis of water samples followed the methods described in Strickland & Parsons (1968). Sediment samples were also collected and subsequently analysed for granulometry, organic matter and carbonate contents.

Tabl. I. – Particle-size categories used to classify sediment types in present study.

Size class	Diameter (mm)	Sediment classification
1	> 2	Gravel
2	1 to 2	Coarse sand
3	0.5 to 1	Medium sand
4	0.250 to 0.5	Medium sand
5	0.125 to 0.250	Fine sand
6	0.063 to 0.125	Silt
7	0.002 to 0.063	Silt
8	< 0.002	Clay

For each sediment sample particles were ranked into eight size categories (table I) :

The organic mater contents in the sediments was calculated after destruction in a muffle furnace (24 hours at 500°C).

In the laboratory the organisms were separated, preserved in 70 % ethanol or in 4 % neutralized formol, according to the presence or absence of calcareous parts, and identified and counted.

Data analysis

Data on both hard and soft substrates and on winter and summer situations were assumed to correspond to different ecological conditions, and therefore were analysed separately.

With regard to biological data, species x stations matrices were analysed, considering data on each sampling site as a whole. The goal of the analysis was to study the horizontal distributional ecology of the species along the estuary, and to reveal differences between the two estuarine arms with regard to communities structure. A first analysis was achieved taking into consideration all the species, and a second one overlooking the species found only once (Legendre & Legendre, 1984).

On hard substrates, since it was not possible to collect water in each sampling level, water samples for determination of physicochemical factors were always taken from the water column (one sample per station). On soft substrates, because of water retention in pools during low tide, it was always possible to get water and sediment samples in each sampling level. Consequently, in the first case, we analysed factors x stations matrices, while in the second case the analysis was based upon factors X samples matrices.

Data underwent principal component analysis (PCA), using the sampling stations or the samples as operational units in the space of biological or physicochemical variables. Sediment granulometric fractions (expressed in %) and dissolved oxygen (% of saturation) were submitted to angular transformation. Eigenvalues and eigenvectors of correlation matrices between variables were computed after centering and reduction to unit variance (Legendre & Legendre, 1984). Correlation matrices were computed using the Pearson's correlation index. In addition, biological data was submitted to cluster analysis, using the Chi-Square distance coefficient (Lebart *et al.*, 1984). (Q mode analysis) and the unweighted pair group mean of analysis (UPGMA) clustering method (Legendre & Legendre, 1984). Data treatment was performed with the NTSYS-PC 1.60 software system (Rohlf, 1990).

Finally, in order to get information on species richness and evenness in different estuarine areas, the values of the Shannon-Wienner heterogeneity index (Legendre & Legendre, 1984; Peet, 1974) were calculated for each sampling station in winter and summer situations.

RESULTS

We identified 90 macrofaunal species from samples carried out in winter and summer situations (table II). A first look to data confirmed our primary assumptions for data analysis, showing that 34 taxa (38 %) were found only in the winter, while 19 (21 %) were found exclusively in the summer, reflecting a seasonal variation in the species composition. Moreover, 36 taxa (40 %) were found exclusively on hard substrates, while 24 (27 %) occurred only in soft substrates, exhibiting a different species composition as a function of the type of substrate.

Hard substrates community

Winter situation

PCA of species x stations data (Fig. 2 A) shows a clear separation between stations located near the mouth (group A) and stations located inside the estuary (groups B and C) along the first axe. A separation between stations from the southern arm (group C) and stations from the northern arm, together with a few stations located near the mouth (group B), is evident along the second axe. Near the mouth, sessile marine species like *Chthamalus stellatus* and *Mytilus galloprovincialis* are very abundant, and significant populations of *Montacuta ferruginosa*, *Idotea pelagica*, and *Hyale stebbingi*, all marine species, together with less important populations of *Littorina neritoides*, *Ballanus perforatus*, *Idotea chelipes*, *I. granulosa*, *Jaera forsmani*, *Amphithoe ramondi*, *A. rubricata*, and *Pachygrapsus marmoratus* are also found. In the inner areas of the

Tabl. II. – List of the *taxa* identified in winter and summer situations, and on both hard and soft substrates. For each *taxa*, the average density (number of individuals.m^{-2}) is given.

TAXA	WINTER		SUMMER	
	Hard Substrates	Soft Substrates	Hard Substrates	Soft Substrates
TURBELLARIA				
Convoluta sp.		0.7	0.4	0.6
NEMERTINI				
Lineus sp.	4.2			
Oerstedia sp.		2.8	0.4	
Tetrastemma sp.		3.5	2	0.6
Palaenemertea				0.6
OLIGOCHAETA		0.7		
POLYCHAETA				
Eteone picta		6.3		
Glycera convoluta		4.2		
Lepidonotus clava			0.4	
Nephthys cirrosa		0.7		
Hediste diversicolor	10.8	661	13.2	890
Neanthes irrorata		2.8	0.4	
Phyllodoce sp.	1.4			
Polydora sp.			2.9	
Amage adspersa		34.6	2	128
Amphictheis gunneri		17		
Capitella capitata		4.8	0.8	30.3
Cirratulus cirratus	0.5			
Heteromastus filiformis		72.9		
Lagis koreni		2.8		
Mercierella enigmatica			4.4	
Pomatocerus triqueter	9.4	0.7		
Pseudomalacocerus cantabra		8.4		
Pygospio elegans		0.7		
Sabellaria alveolata	2.4			
Spio filicornis		3.5		3.7
Streblospio dekhuyzeni		24.5	2.4	23.9
Sabellidae			0.4	
POLYPLACOPHORA				
Lepidochitona cinereus	0.5			
GASTROPODA				
Bittium reticulatum				0.6
Cerithium vulgatum				0.6
Gibbula umbilicalis				0.6
Haminea hydatilis	30	200		0.6
Hydrobia ulvae	52.2	1980	181	859
Littorina littorea	0.5	15.4		10
Littorina neritoides	2.8			
Littorina saxatilis				0.6
Murex trunculus	0.9			
Nassarius reticulatus				5
Nucella lapillus			0.4	
Odostomia unidentata	0.9			
Patella aspera	0.5			
Patella lusitanica	1.4			
Rissoa membranacea	0.5			
Rissoa parva	0.9			1.3
Cerastoderma edule		66.6	2.8	36
Montacuta ferruginosa	32.9	0.7		
Mytilus galloprovincialis	5790	4.9	1390	
Scrobicularia plana	1.9	283	4.8	103
ANOSTRACA				
Artemia salina		0.7		
CIRRIPEDIA				
Ballanus perforatus	11.8			
Chthamalus stellatus	764		1470	
ISOPODA				
Cyathura carinata	0.9	322	11.2	128
Dynamene bidentata	0.5		2.4	
Gnathia vorax	0.5			
Eurydice pulchra				0.6
Eurydice spinigera				0.6
Idotea chelipes	3.8	0.7		
Idotea granulosa	3.3		1.6	0.6
Idotea pelagica	64.9	0.7	37.6	
Jaera forsmani	9.9		63.6	
Sphaeroma hookeri	24.4	0.7	10.4	1.8
AMPHIPODA				
Amphithoe valida	1.4			
Amphithoe ramondi	3.3			
Amphithoe rubricata	3.4			
Bathyporeia sarsi		1.4		1.3
Corophium insidiosum	33.1		2.8	
Corophium multisetosum		3.4		5.7
Echinogammarus marinus	196	12.6	951	3.1
Echinogammarus stoerensis			68.4	1.6
Gammarus chevreuxi	1.4	1.4		
Gammarus locusta	2.6		6.4	
Haustorius arenarius		0.7		
Hyale crassipes	3.3			
Hyale perieri	2.8			
Hyale stebbingi	184		117	
Jassa marmorata			0.4	
Leptocheirus pilosus	44.7		88.4	
Melita palmata	88.9	19.1	66.8	11.9
Talorchestia sp.			8.4	
MYSIDACEA				
Paramysis helleri				1.9
DECAPODA				
Carcinus maenas	13.2	13.3	80	15
Crangon crangon		2	7.6	11.3
Pachygrapsus marmoratus	6.6		1.2	
Palaemonetes varians	0.9	0.7	2.8	1.8
INSECTA				
Diptera larvae	4.2	9.1	86.4	3.7
Lepidoptera larvae				1.6
PISCES				
Blennius sp. 1	0.5			
Blennius sp. 2	0.5			
Pomatoschistus sp.	0.5	0.7		1.9

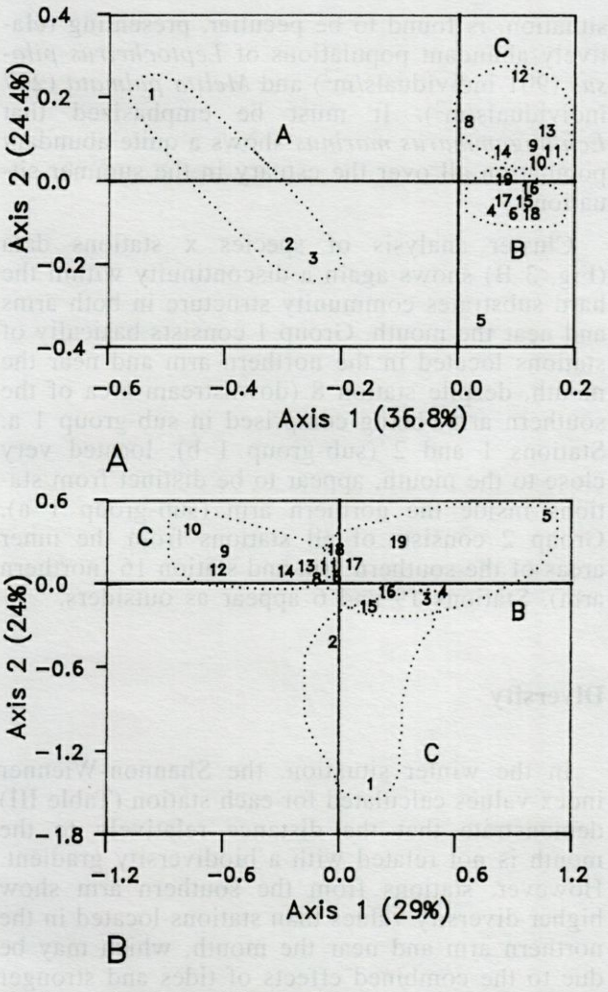

Fig. 2. – Analysis of hard substrates community structure from PCA of species x stations matrices overlooking species found only once. A – winter situation : Projection of stations against the first two axes, r = 0.88934. B – summer situation : Projection of stations against the first two axes, r = 0.85206. The percentage of variability explained by the principal axes is given. Groups of stations pointed out are discussed in the text.

estuary, *Mytilus galloprovincialis* and *Chthamalus stellatus* populations become much less dense, and the presence of other typical marine species is inconspicuous. Station 1, which exhibits the strongest marine influence (typical estuarine species are represented only by sparse populations of *Echinogammarus marinus* and *Carcinus maenas*), presents dense populations of *Mytilus galloprovincialis*, *Chthamalus stellatus*, and *Hyale stebbingi*. The separation of stations from both estuarine arms along the second axe is mainly due to the preferential occurrence of *Leptocheirus pilosus* and *Melita palmata*, followed by *Sabellaria alveolata*, in stations from the northern arm, and of *Echinogammarus marinus*, *Sphaeroma hookeri*, and *Hediste diversicolor* (frequently found in sediment deposits over rock), followed by *Idotea chelipes*, *I. pelagica*, *Amphithoe ramondi*, *A. rubricata*, and *Carcinus maenas*, in stations from the southern arm.

Station 5, located near the connection of the two arms, appears to be peculiar, exhibiting significant densities of *Melita palmata* (704 individuals/m^2) and *Leptocheirus pilosus* (437 individuals/m^2) populations. Typical estuarine species like *Hydrobia ulvae*, *Echinogammarus marinus*, *Sphaeroma hookeri*, and *Carcinus maenas* show higher abundances in the southern arm, while *Mytilus galloprovincialis* and *Chthamalus stellatus* populations are significant in

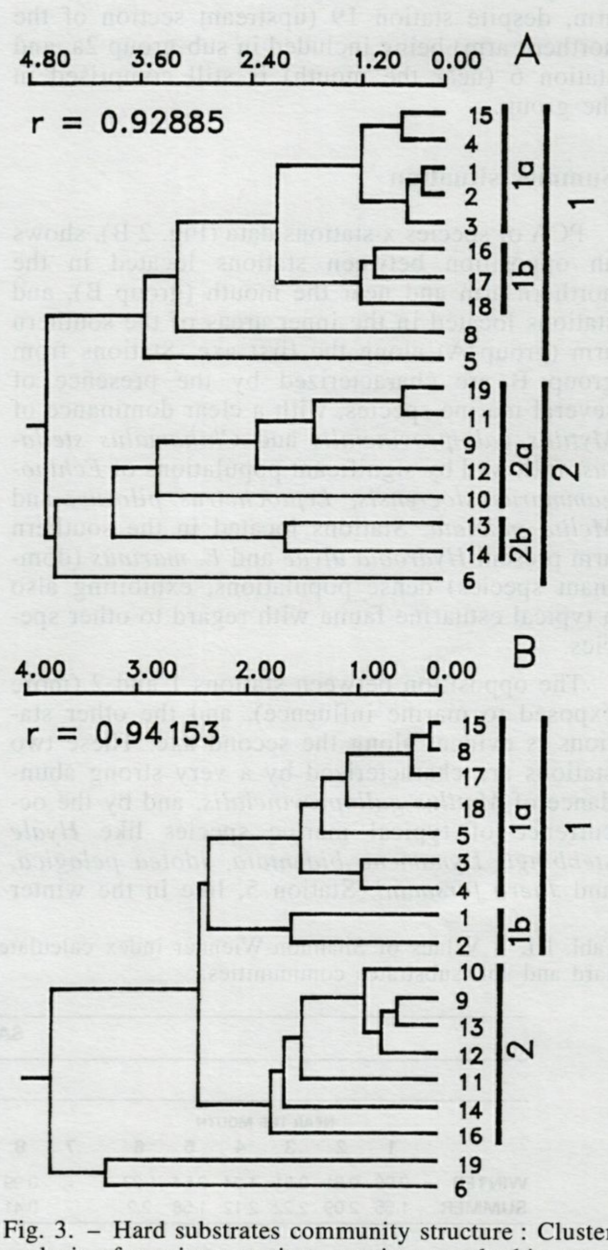

Fig. 3. – Hard substrates community structure : Cluster analysis of species x stations matrices overlooking species found only once. Data analysed using the Chi-Square distance coefficient (Q mode analysis) and the UPGMA clustering method. A – winter situation; B – summer situation. Values of cophenetic correlation coefficients are indicated.

the northern arm (although less abundant than in stations located near the mouth) and very scarce in the southern arm.

Cluster analysis of species x stations data (Fig. 3 A) allows to recognize a structural discontinuity in the communities from both arms and near the mouth, corroborating therefore the results from ordination. Group 1 consists of stations located near the mouth (basically sub-group 1a) and inside the northern arm (sub-group 1b), together with stations 8 and 5, located in the down stream section of the southern arm. Group 2 consist primarily of stations from inner areas of the southern arm, despite station 19 (upstream section of the northern arm) being included in sub-group 2a, and station 6 (near the mouth) is still comprised in the group.

Summer situation

PCA of species x stations data (Fig. 2 B), shows an opposition between stations located in the northern arm and near the mouth (group B), and stations located in the inner areas of the southern arm (group A) along the first axe. Stations from group B are characterized by the presence of several marine species, with a clear dominance of *Mytilus galloprovincialis* and *Chthamalus stellatus*, followed by significant populations of *Echinogammarus stoerensis, Leptocheirus pilosus*, and *Melita palmata*. Stations located in the southern arm present *Hydrobia ulvae* and *E. marinus* (dominant species) dense populations, exhibiting also a typical estuarine fauna with regard to other species.

The opposition between stations 1 and 2 (more exposed to marine influence), and the other stations is evident along the second axe. These two stations are characterized by a very strong abundance of *Mytilus galloprovincialis,* and by the occurrence of typical marine species like *Hyale stebbingi, Dynamene bidentata, Idotea pelagica*, and *Jaera forsmani*. Station 5, like in the winter situation, is found to be peculiar, presenting relatively abundant populations of *Leptocheirus pilosus* (901 individuals/m^2) and *Melita palmata* (267 individuals/m^2). It must be emphasized that *Echinogammarus marinus* shows a quite abundant population all over the estuary in the summer situation.

Cluster analysis of species x stations data (Fig. 3 B) shows again a discontinuity within the hard substrates community structure in both arms and near the mouth. Group 1 consists basically of stations located in the northern arm and near the mouth, despite station 8 (downstream area of the southern arm) being comprised in sub-group 1 a. Stations 1 and 2 (sub-group 1 b), located very close to the mouth, appear to be distinct from stations inside the northern arm (sub-group 1 a). Group 2 consists of all stations from the inner areas of the southern arm and station 16 (northern arm). Stations 19 and 6 appear as outsiders.

Diversity

In the winter situation, the Shannon-Wienner index values calculated for each station (Table III) demonstrate that the distance relatively to the mouth is not related with a biodiversity gradient. However, stations from the southern arm show higher diversity values than stations located in the northern arm and near the mouth, which may be due to the combined effects of tides and stronger fresh water discharge along the northern arm, creating a significant daily environmental stress for environmental factors.

On the other hand, in the summer situation, the Shannon-Wienner index values calculated for each station (Table III) reveal several differences as compared to the winter situation. In the summer, the highest values for diversity are found near the mouth of the estuary, while the lowest values are found inside the southern arm.

Tabl. III. – Values of Shannon-Wienner index calculated for each station in winter and summer situations and for hard and soft substrates communities.

	SAMPLING STATIONS																		
	Hard substrates																		
	NEAR THE MOUTH									SOUTH ARM					NORTH ARM				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
WINTER	0.98	0.61	0.81	1.24	2.54	1.23	-	0.99	1.07	1.21	1.26	2.31	1.16	1.94	1.11	2.27	0.35	0.62	1.2
SUMMER	1.55	2.09	2.22	2.12	1.58	2.2	-	0.41	0.78	1.21	1.4	0.73	1.12	1.07	0.78	0.99	0.97	1.5	3.0
	Soft substrates																		
	NEAR THE MOUTH									SOUTH ARM					NORTH ARM				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
WINTER	1.0	1.39	-	-	-	1.52	2.32	1.5	2.69	2.19	1.96	1.43	1.91	1.71	2.13	3.08	1.6	2.01	1.52
SUMMER	0.92	0.76	-	-	-	-	2.65	1.83	2.3	1.6	2.08	1.36	1.19	1.62	1.51	1.45	0.66	1.38	0.54

With regard to hard substrates community, a decrease in diversity was observed in the southern arm from winter to summer, while an increase occurred in the northern arm and near the mouth. The decrease in diversity observed in the southern arm may be explained by the change in biological activity of *Echinogammarus marinus*, which becomes extremely abundant in the summer situation (average about 3 000 individuals/m^2 in the southern arm on the *Fucus* covered areas), affecting species evenness.

Soft substrates community

Winter situation

PCA of species x stations data (Fig. 4 A) shows the oppositon between stations 7, 9, 10, and 11

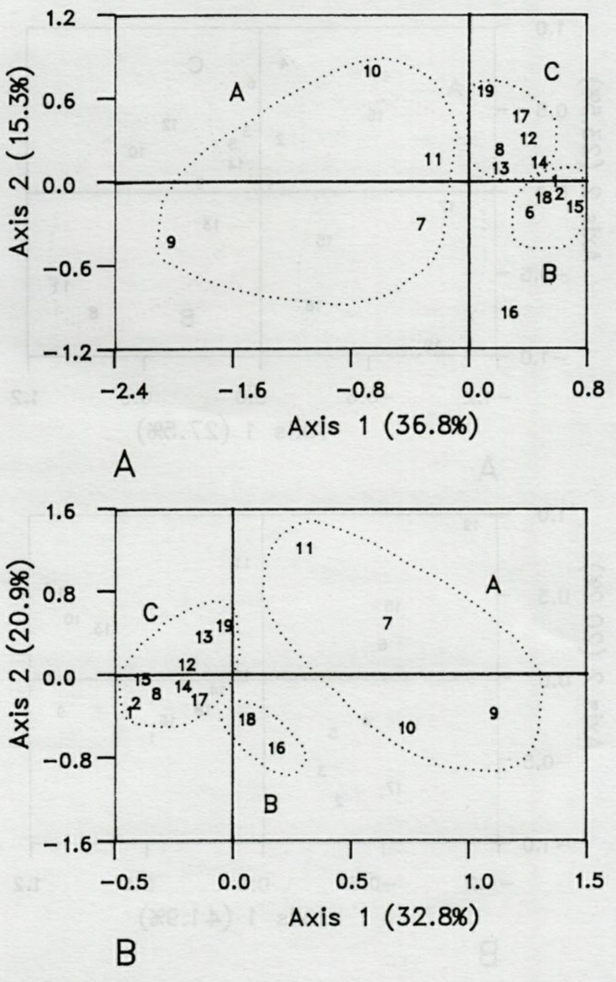

Fig. 4. – Analysis of soft substrates community structure from PCA of species x stations matrices overlooking species found only once. A – winter situation : Projection of stations against the first two axes, r = 0.80878. B – summer situation : Projection of stations against the first two axes, r = 0.87681. The percentage of variability explained by the principal axes is given. Groups of stations pointed out are discussed in the text.

(group A), located in the southern arm, corresponding to *Spartina maritima* and *Zostera noltii* marshes, and stations without vegetal covered areas (groups B and C) along the first axe. These stations differ from the others in that several species (e.g. *Amage adspersa, Heteromastus filiformis, Hediste diversicolor, Hydrobia ulvae, Cerastoderma edule, Scrobicularia plana,* and *Cyathura carinata)* present considerably higher population abundances. Along the second axe we can distinguish between stations located in the southern arm (8, 12, 13, and 14), followed by stations 17 and 19 (northern arm) (group C), and stations located in the northern arm and near the mouth of the estuary (group B). Stations from the southern arm, even those located in areas without vegetal cover, present higher population abundances than stations from the northern arm, namely with regard to common species like *Hediste diversicolor, Hydrobia ulvae, Scrobicularia plana,* and *Cyathura carinata*. Station 16, located in the northern arm, is clearly separated along the second axe, which is explained by the sporadic occurrence of several rare species in the estuary like *Eteone picta, Glycera convoluta*, and *Spio filicornis*.

Cluster analysis of species x stations data (Fig. 5 A) does not reveal a clear discontinuity within the soft substrates community. Actually, a single main group of stations is recognizable (group 1), consisting of stations from both estuarine arms, while stations 1, 2 and 6, located near the mouth, appear as outsiders. Nevertheless, stations 9, 11, 10 and 7, located in *Spartina maritima* and *Zostera noltii* marshes, are clearly assembled (sub-group 1 b), which agrees with results from ordination.

Summer situation

PCA of species x stations data (Fig. 4 B) shows once more the opposition between stations corresponding to *Spartina maritima* and *Zostera noltii* marshes (group A) and stations without vegetal covered areas (groups B and C) along the first axe. Like in the winter situation, the most important species contributing to the observed variability are *Amage adspersa, Heteromastus filiformis, Hediste diversicolor, Hydrobia ulvae, Cerastoderma edule, Scrobicularia plana*, and *Cyathura carinata* (positive side of factor 1), which populations are much more abundant in stations from group A as compared to other areas. Contrarily to the winter situation, differences between stations located in the southern arm and stations located in the northern arm are not evident. This may be due to the increase of marine influence inside the estuary in the summer, determining the occurrence of more uniform conditions.

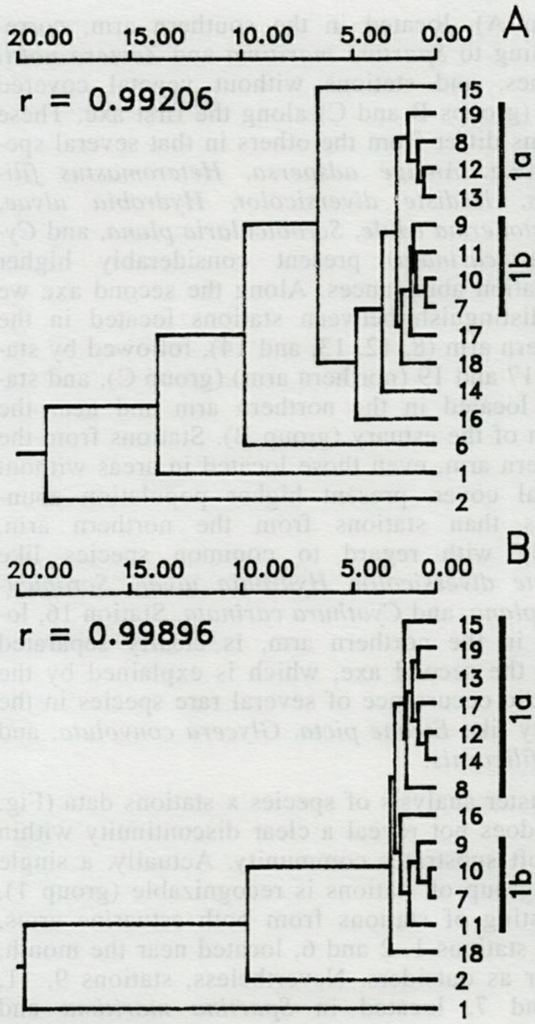

Fig. 5. – Soft substrates community structure : Cluster analysis of species x stations matrices overlooking species found only once. Data analysed using the Chi-Square distance coefficient (Q mode analysis) and the UPGMA clustering method. A – winter situation; B – summer situation. Values of cophenetic correlation coefficients are indicated.

Cluster analysis of species x stations data (Fig. 5 B), like in the winter situation, does not bare a discontinuity within the soft substrates community, and again a single group of stations is recognizable (group 1), consisting of stations from both estuarine arms. Stations 2, and 1, located very close to the mouth, appear as outsiders. Again like in the winter situation, stations 9, 10, 7 and 11, located in *Spartina maritima* and *Zostera noltii* marshes, are assembled (sub-group 1 b), corroborating results from ordination.

Diversity

The Shannon-Wienner index values calculated for each station in both winter and summer situations (Table III) are consistently higher in stations located in *Spartina maritima* and *Zostera noltii* marshes, which emphasizes their favourable conditions for the development of abundant populations and higher biodiversity. However, differences between other estuarine areas and seasonal variations in diversity are not outstanding.

Physical and chemical parameters

With regard to the winter situation, PCA of water physicochemical factors x stations matrices (Fig. 6 A) reveals a clear separation between stations from the northern and southern arms (groups A and B respectively) along the first axe, and a gradient from the mouth (group C) to inner areas of the estuary along the second axe. The variability along the first axe is mainly explained by the distribution pattern of dissolved oxygen and nitrates concentration values (negative side of factor 1),

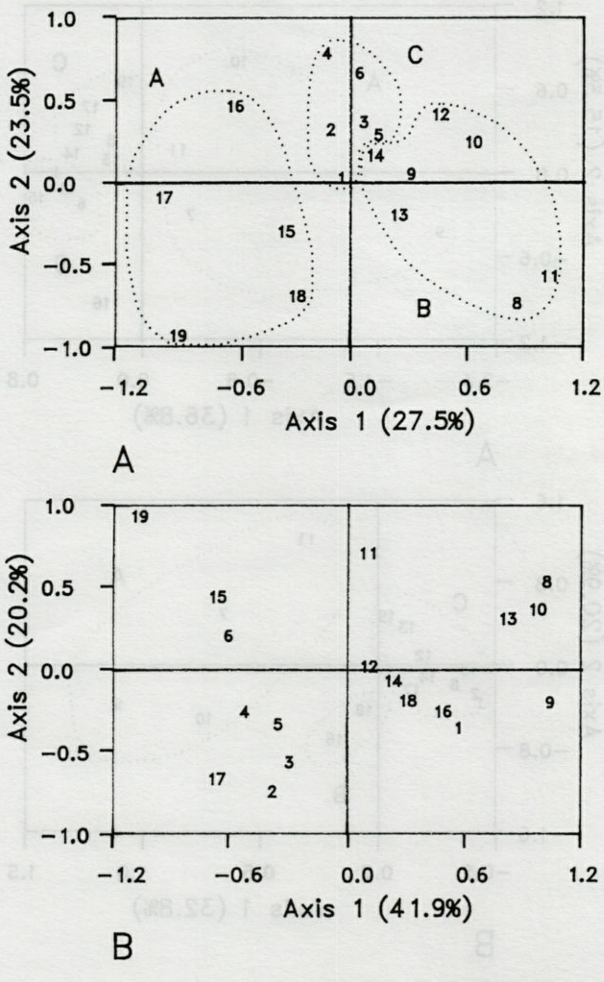

Fig. 6. – Analysis of physicochemical factors of the water from PCA of factors x stations matrices. A – winter situation : Projection of stations against the first two axes, r = 0.94057. B – summer situation : Projection of stations against the first two axes, r = 0.93314. The percentage of variability explained by the principal axes is given. Groups of stations pointed out are discussed in the text.

and of salinity and temperature values (positive side of factor 1). Along the second axe, variability is mainly explained by the distribution of salinity, temperature and nitrites values (negative side of factor 2), and of pH (positive side of factor 2). Actually, it is very clear the opposition along the first axe between stations from the northern arm, presenting lower salinities (20.8 ± 6.8 ‰) (average ± standard deviation) more stable temperatures (12 ± 0.5ºC) and higher concentrations of dissolved oxygen (76.5 ± 11.6 ‰ of saturation) and nitrates (0.32 ± 0.18 mg liter^{-1}) during low tide, and stations from the southern arm, presenting higher salinities (22.9 ± 6.7), more variable temperatures (12.9 ± 24ºC), and lower dissolved oxygen (70.6 ± 7.1 %) and nitrates concentrations (0.16 ± 0.09 mg.liter^{-1}).

These results can be explained taking into consideration the hydraulic circulation in the estuary. In the northern arm, the water circulation depends on tides and on the freshwater discharge, determining a faster renewal of the water mass, and consequently higher values of dissolved oxygen. Moreover, since samples were taken during low tide, the river discharge (transporting nutrients from agricultural areas) determined the occurrence of lower salinities and higher nitrates concentration in the northern arm and areas near the mouth. The smaller depth may explain larger temperature ranges found in the southern arm. Finally, the lower concentration of nitrates in the southern arm may be a function of the smaller freshwater discharge.

Due to marine influence, temperature and pH values seem to be more uniform near the mouth of the estuary (7.4 ± 0.4), and nitrites concentration to be low (0.006 ± 0.002 mg.liter^{-1}) (probably as a function of stronger oxygenation of the water column).

In the summer situation, the analysis of physicochemical factors of the water do not show conspicuous differences between stations located in both estuarine arms and near the mouth (Fig. 6 B). Stations 2, 3, 4, 5, 6, 15, 17 and 19 (in the northern arm and near the mouth) are opposed to stations 1, 8, 9, 10, 11, 12, 13, 14, 16 and 18 (in the northern arm, southern arm, and near the mouth) along the first axe. The variability along the first axe is mainly explained by lower salinities (25 ± 2.1 ‰) and higher values of dissolved oxygen (92.8 ± 6.1 %), pH (7.8 ± 0.3) and nitrites (0.01 ± 0.002 mg.liter^{-1}) found in stations from the negative side of factor 1, and by higher salinities (27.3 ± 2.4 ‰) found in stations from the positive side of factor 1.

Along the second axe, stations from the inner areas of both arms (8, 10, 11, 12, 13, 15 and 19) are partially separated from stations located in the downstream section of the northern arm and near the mouth. Temperature is the factor that contributed the most for this partial separation. Actually, higher temperatures of the water found in estuarine inner areas may be explained by the smaller depth as compared to areas near the mouth.

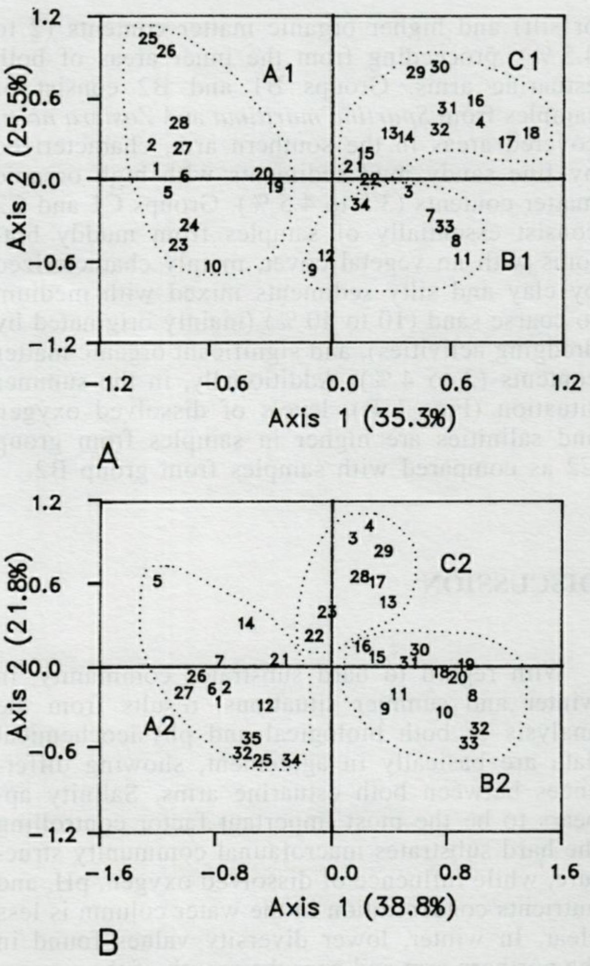

Fig. 7. – Analysis of physicochemical factors of water and sediments from PCA of factors x samples matrices. A – winter situation : Projection of samples against the first two axes, r = 0.91314; B – summer situation : Projection of samples against the first two axes, r = 0.94261. The percentage of variability explained by the axes is given. Groups of samples pointed out are discussed in the text.

PCA of water sediments physicochemical factors x samples matrices shows similar results with regard to winter (Fig. 7 A) and summer (Fig. 7B) situations. In both cases, projection of samples against the first two axes of variability allow to consider three distinct equivalent groups. Groups A 1 and A 2 correspond mainly to samples obtained on fine or medium sand bottoms with small organic matter contents (0 to 1.5 %), proceeding from the lower limits of the eulittoral zone (low water level) in the downstream sections of both arms and near the mouth (sand pole). Groups B1, B2, C1 and C2 correspond to samples from bottoms with large fractions of fine particles (clay or silt) and higher organic matter contents (2 to 4.5 %), proceeding from the inner areas of both estuarine arms. Groups B1 and B2 consist of samples from *Spartina maritima* and *Zostera noltii* covered areas in the southern arm, characterized by fine sandy mud sediments with high organic matter contents (3.5 to 4.5 %). Groups C1 and C2 consist essentially of samples from muddy bottoms with no vegetal cover, mainly characterized by clay and silty sediments mixed with medium to coarse sand (10 to 40 %) (mainly originated by dredging activities), and significant organic matter contents (2 to 4 %). Additionally, in the summer situation (Fig. 7 B), levels of dissolved oxygen and salinities are higher in samples from group C2 as compared with samples from group B2.

DISCUSSION

With regard to hard substrates community, in winter and summer situations, results from the analysis of both biological and physicochemical data are basically in agreement, showing differences between both estuarine arms. Salinity appears to be the most important factor controlling the hard substrates macrofaunal community structure, while influence of dissolved oxygen, pH, and nutrients concentration in the water column is less clear. In winter, lower diversity values found in the northern arm and near the mouth of the estuary may be due to the combined effects of tides and freshwater discharge, causing strong daily variations in physicochemical factors. From winter to summer, the decrease in freshwater discharge, and consequently the easier tidal penetration, seems to favour the incursion of epifaunal marine species (e.g. *Dynamene bidentata, Echinogammarus stoerensis, Jassa marmorata, Pachygrapsus marmoratus*) inside the estuary and especially along the northern arm. Despite their sparse populations, the intrusion of these species may explain the observed increase in diversity.

The hydraulic circulation in the southern arm depends essentially on tides and on the freshwater discharge of the Pranto river. Consequently, in the summer situation, due to evaporation during low water, salinity values are higher in the southern arm as compared with the northern arm and areas near the mouth. Both daily and seasonal salinity changes are less important in the southern arm (Marques, 1989), which can nevertheless change through the year, from mesohaline (winter situation) to polyhaline conditions (summer situation). The southern arm presents therefore favourable environmental conditions for true estuarine organisms, as defined in McLusky (1989). That is the case of *Echinogammarus marinus*, a key species in the *Fucus spp.* covered areas (Marques & Nogueira, 1991), which exhibits important population abundances all over the estuary during summer, although appearing more limited to the southern arm in the winter. Therefore, the small decrease in species diversity observed from winter to summer in the southern arm does not correspond to a reduction in species richness, but apparently to an increase of biological activity, since the enhancement of *Echinogammarus marinus* population undoubtedly decreased species evenness.

With regard to soft substrates community, we found also a good agreement between results from the analysis of biological and physicochemical data in both winter and summer situations. The sediment particles size appears to be the most important factor controlling organisms distribution, although organic matter contents, salinity, and dissolved oxygen still seem to play an important role. In fact, higher fractions of fine particles (0.125 mm) and higher organic matter contents tend to correspond to enhanced populations of the most common and abundant species in the estuary (e.g. *Hediste diversicolor, Hydrobia ulvae, Scrobicularia plana*, and *Cyathura carinata*). Whereas involving other species, a similar situation was observed in other estuaries (Andrade, 1986; Dauer *et al.*, 1987). Temperature, pH, and nutrients concentration in the water seem to have little influence. Nevertheless, although all the water samples were taken over periods of 3 hours around low water time, sampling was not really simultaneous, which surely introduced a bias into the results since tidal effects, especially near the mouth, can change very rapidly the values of physicochemical factors.

In the *Spartina maritima* and *Zostera noltii* marsches, primarily located in the middle section of the southern arm, the most common and abundant species (e.g. *Amage adspersa, Heteromastus filiformis, Hediste diversicolor, Hydrobia ulvae, Cerastoderma edule, Scrobicularia plana*, and *Cyathura carinata*) present enhanced populations as compared to other areas, and biodiversity is higher. A similar trend have also been observed in other estuarine systems, particularly in *Zostera* covered areas (Almeida, 1988; Whitfield, 1989). Actually, *Zostera sp.* is a macrophyte with roots which can only take up nutrients from the sediments. Consequently, the formation of hydrogen sulphide in the sediments becomes much less important in these areas, and the redox discontinuity layer occurs deeper in the sediments. Therefore, although living *Zostera* is normally not an important food item for macroinvertebrates (Whitfield, 1989), it may provide good conditions for zoobenthos populations.

CONCLUSIONS AND OUTLOOKING

The analysis of both hard and soft substrates communities structure showed clear differences between the two arms of the Mondego estuary, namely with regard to populations abundance and biodiversity. In both cases a good agreement was found between results from the analysis of biological and physicochemical data.

The observed differences are most probably due to very dissimilar hydrographic characteristics of the two arms. The southern arm is still less affected by human activities and presents more favourable environmental conditions for the development of enhanced populations of true estuarine species. Nevertheless, the southern arm is also shallower than the northern arm, and water circulation depends widely on tides, especially in the summer. For these reasons, we consider that the southern arm appears potentially much more exposed to environmental changes.

Salinity appears to be the most important factor controlling the hard substrates community structure, while sediments granulometry is the most important factor controlling the distributional ecology of soft substrates macrofauna, followed by organic matter contents, salinity, and dissolved oxygen. Other studied factors seem to play a less important role with regard to macrofauna distribution.

Spartina maritima and *Zostera noltii* marshes appear to be the richest areas with regard to macrofauna abundance and biodiversity. However, occasional blooms of *Enteromorpha spp.* have been observed in the southern arm, probably as a function of excessive nutrients release into the estuary. Since macrophytes have roots and are only able to take up nutrients from the sediments, it seems possible that macroalgae like *Enteromorpha*, which is able to take up nutrients directly from the water, can take advantage from this situation. Therefore, it seems also likely that an eutrophication process might take place in the southern arm, and in such a case a shift in the benthic primary producers could occur, affecting the structure and functioning of the trophic chain and ultimately the species composition in the community. The present results concern a limited period, and therefore further work will be necessary in order to monitor changes and determine the evolutive trends of the macrobenthic communities in the Mondego estuary.

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