CHARACTERIZATION OF THE TAGUS ESTUARY MACROBENTHIC COMMUNITIES

By JOSÉ CALVÁRIO [1]

With 14 figures and 2 tables

ABSTRACT. According to the Portuguese National Commission for Environment, the average values of the physical and chemical parameters of the water in the Tagus estuary present a typical longitudinal gradient, related to the distance from the estuary mouth. The structure and distribution of the macrozoobenthic communities are both a function of hydrological and sedimentological factors. These factors determine the presence of the species, and interfere with their distribution along the estuary. The sectorial average values of biological descriptors progress according to the longitudinal-vertical gradients, recording a decrease in the species richness, abundance and biomass upstream from the mouth, and from the intertidal zone to the sublittoral zone. The species diversity and the evenness, decrease in the same direction translating into an increased imbalance of the community structures. The sublittoral mud communities of estuary terminal zone and the intertidal oyster-bed communities present values of species diversity and evenness above average, denoting the presence of structurally well balanced communities in these biotopes. The Tagus estuary satisfies the definition of an euryhaline-eurythermic biocenosis, in the sense that the constant association of *Nereis* (*Hediste) diversicolor* - *Scrobicularia plana* - *Cyathura carinata* seems to correspond to the European estuary communities already described.

KEY WORDS: hydrological and sedimentological gradients, benthic macrofauna, community structure, estuaries, Portugal.

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RESUMO. De acordo com a Comissão Nacional do Ambiente (Portugal), os valores médios dos parâmetros fisico-químicos da àgua do Estuário do Tejo apresentam um típico gradiente longitudinal, relativo à distância da fôz. Tanto a estrutura como a distribuição das comunidades macrobentónicas são ambas função de factores hidrológicos e sedimentológicos. Estes factores determinam a presença das espécies, e interferem com a sua distribuição ao longo do estuário. Os valores médios sectoriais dos descritores biológicos distribuem-se segundo um gradiente longitudinal-vertical, com um decréscimo da riqueza específica, abundância e biomassa de montante para jusante, e da zona intertidal para a zona subtital. A diversidade específica e a equitabilidade decrescem igualmente no mesmo sentido traduzindo um crescente desiquilíbrio da estrutura das comunidades. As comunidades das vasas sublitorais na zona terminal do estuário e as comunidades intertidais das ostreiras apresentam valores de diversidade específica e equitabilidade acima da média, traduzindo a presença de comunidades estruturalmente bem equilibradas nestes biótopos. No Estuário do Tejo a associação de *Nereis (Hediste) diversicolor* – *Scrobicularia* – *Cyathura carinata* traduzindo a presença de uma biocenose eurihalina-euritérmica atlântica, parece corresponder às comunidades descritas por outros autores para estuários europeus.

INTRODUCTION

The Tagus estuary occupies an area of about 320 Km^2 and receives water from several tributaries. About 30 to 34 x 10^3 hectares of its area are flooded at low and high tide, respectively. It is connected to the sea by three mesotidal bars of variable depth. The average tidal amplitude is between 1,33 (MLW) and 3,99 m (MHW). In each tide cycle the estuary presents a tidal prism of about 750x10^6 m^3 for an average tide.

The area studied corresponds to the Mesohaline and Polyhaline sectors of the estuary (Fig.1). In the Mesohaline sector, water salinities are strongly stratified at the surface and vary between 2,8 and 18‰. In the Polyhaline sector, the estuary presents a mixed type, and the salinities vary between 18 and 30‰. These values are altered both on sunny and rainy days. Based on the values observed by the Portuguese National Commission for Environment (CNA), we can verify that the physical and chemical parameters of the water present a longitudinal gradient related to the distance from the estuary mouth. The mean temperature value increases to upstream (15,5^o C - 18,0^o C), while the mean values for salinity (30,0‰ - 2,8‰), pH (7,8 - 6,1), and dissolved oxygen (91,9% - 83%), decrease in the same direction (CNA, 1977, 1978, 1979).

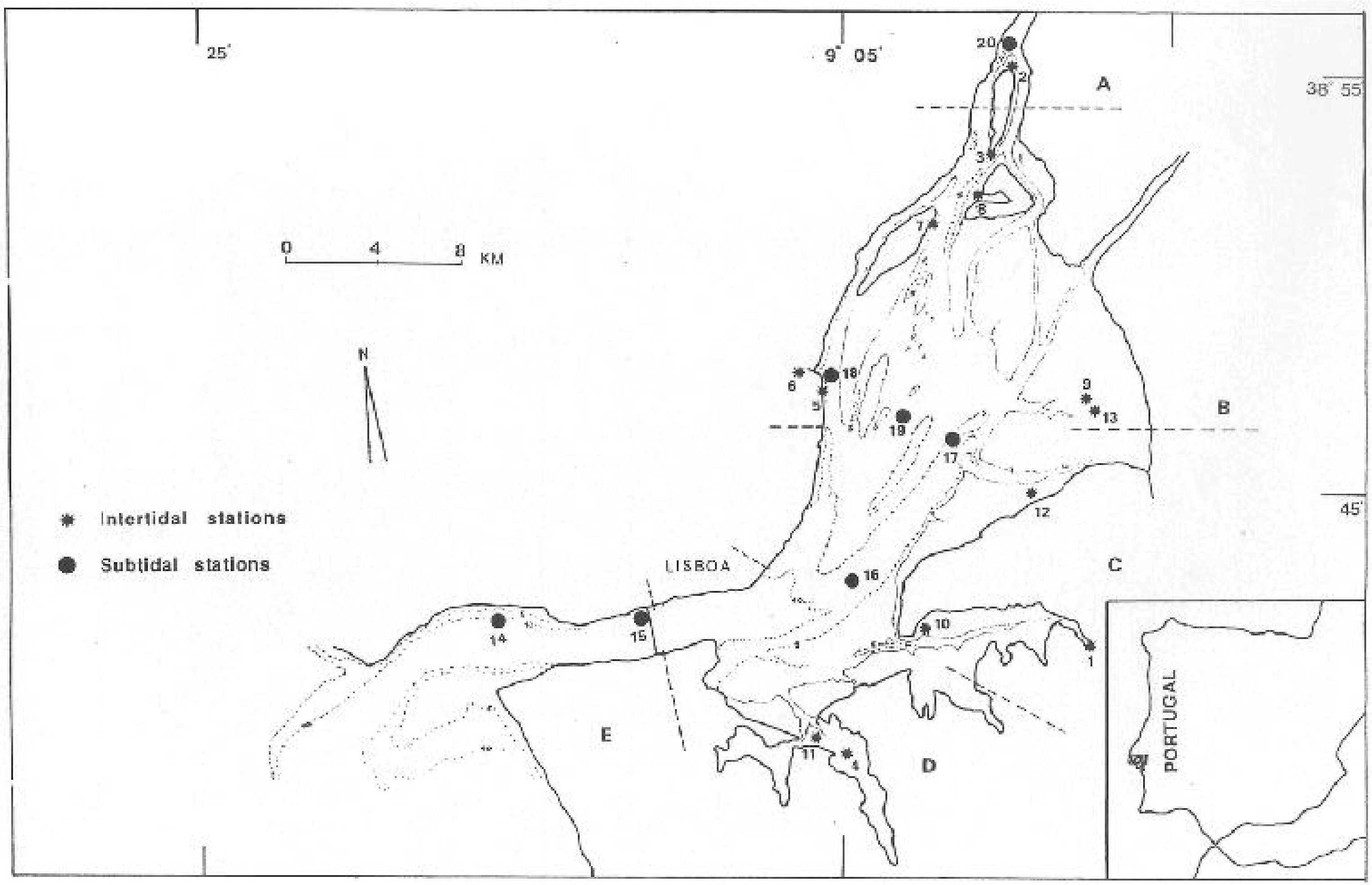

Fig. 1 - Tagus estuary showing sampling locations.

MATERIAL AND METHODS

Sediment and biological samples were collected in each season at 13 intertidal stations (1980), and at 7 sublittoral stations (1981) (Fig. 1).

The biological samples were collected using a Van Veen grab (0,2 m^2) (5 replicates) for the sublittoral stations and a cylinder corer (0,08 m^2) (13 replicates) for the intertidal stations. The samples were sieved through a 1.0 mm mesh. The benthic organisms were separated, preserved, identified and counted. Using a methodology of MARCHAND & ELIE (1983) the estuary was divided into sectors based on the mean salinities:

- Mesohaline sector: A (2,8 - 5‰); B (5 - 15‰); C (15 - 18‰);
- Polihaline sector: D (18 - 25‰); E (25 - 30‰) (Fig. 1).

The granulometry and organic matter of the sediments were determined. The grain-size analysis of sediments was based on a dry-sieving method, and the sediments were graded by their dimensions, according to the Wentworth scale (GRAY, 1981). The sedimentary groups were classified by the percentage of fine particles with a diameter less than 50 µm (Fp%), and according to Roux scale (ROUX,1964): sand (< 5%); muddy sand (5% - 50%); sandy mud (50% - 95%) and mud (> 95%). The organic matter content of the sediments was determined as Organic Nitrogen percentage through C-H-N analyser.

The species' frequency of occurrence relative to the different sedimentary groups and salinity sectors, were calculated according to the constancy (*C' %*) and fidelity (*F' %*) indices (BERMUDEZ, 1980). Species richness (no. specimens. m^{-2}) (*NO*), abundance (no. inds. in habitats) (*N*), density (no. inds. m^{-2}) (*D*) and biomass (g. m^{-2}) (*B*) (total dry weight) were also determined. The Shannon-Wiener's diversity (*H'*) (SHANNON & WEAVER,1963), evenness (*J'*) (PIELOU, 1969) and species dominance (*D' = 1 - J'*) (BAKUS, 1990), were estimated.

RESULTS

Sedimentary gradients

The sediments in the Tagus estuary are mostly composed of silt and clay which originate in the river, or sand, which is of both river and sea origin. The granulometric composition and distribution are correlated to the estuary morphologic and hydrographic characteristics (these have a large rise and fall of tide, fast current velocities, a high area/volume ratio, and especially upstream of the sector E have very intense dynamics due to the semidiurnal tide) (Fig. 2).

Globally, the samples from sedimentary groups were distributed as muds (30,8%), muddy sands (29,6%), sandy muds (24,2%) and muddy detrital sediments (oyster-beds) (15,4%). Muddy sands were dominant in the sublittoral zone due to a higher contribution by the sandy fraction (41,9%), while muds and sandy muds were better represented in the intertidal zone due to a strong presence of silt and clay fractions (74,1%). The gravel fraction was only represented in the intertidal oyster-beds (4,9%) (Table 1). Muds were dominant throughout most of the downstream sector of the estuary (E), while the sandy muds and oyster-beds dominated at the central areas (B, C and D sectors). Muddy sands were more common upstream (A sector) (Fig. 3).

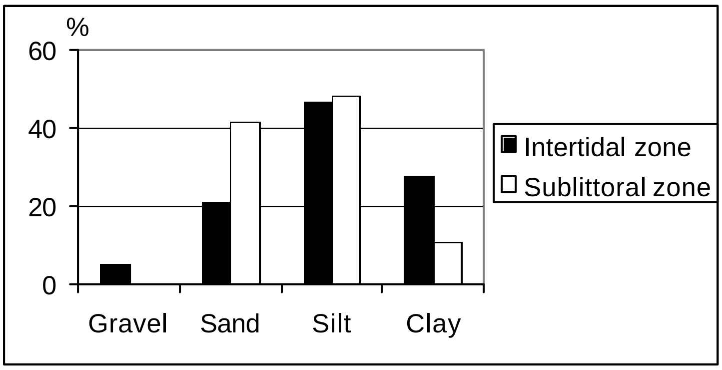

Fig. 2 - Granulometric composition of sediments in estuarine zones.

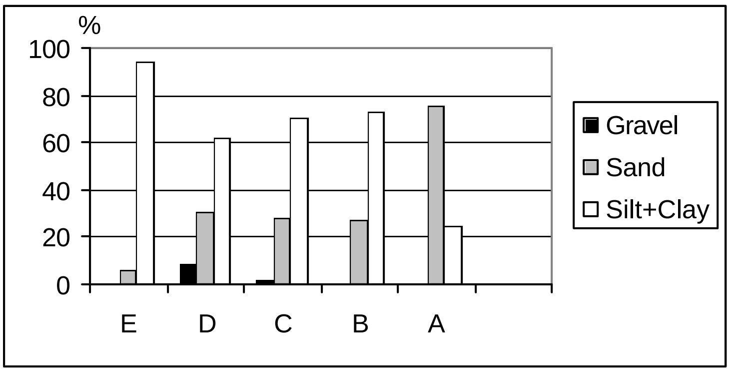

Fig. 3 - The distribution of granulometric composition along the estuary.

Generally, the higher concentrations of organic matter in the sediments (expressed in percentage of Organic Nitrogen) were observed in intertidal areas of mud accumulation (confined, drained and low current muddy zones, oyster-beds). In the sedimentological groups, the muds presented the highest values, followed by the oyster-beds, sandy muds and the muddy sands (Fig. 4). The lower values were observed in upstream (A sector) (Fig. 5).

TABLE 1 - Sediment analysis done at the sampling stations in the Tagus estuary.

	Granulometric composition (%)				Organic Nitrogen (%)	Sedimentary groups
Stations	**Gravel**	**Sand**	**Silt**	**Clay**		
1	*	12,2	15,5	72,3	0,11	Mud
2	*	69,8	29	1,2	0,07	Muddy sand
3	*	44,3	38,1	17,6	0,15	Sandy mud
4	*	22,9	67,1	10	0,13	Sandy mud
5	*	7,1	78,8	14,1	0,17	Mud
6	*	1,2	62,1	36,7	0,18	Mud
7	*	34,7	63	2,3	0,15	Sandy mud
8	*	5,4	17,2	77,4	0,16	Mud
9	*	17,7	54,2	28,1	0,17	Sandy mud
10	13,2	2,2	37	47,6	0,13	Muddy detrital
11	19,8	3,3	75,8	1,1	0,12	Muddy detrital
12	15,1	36,2	34,5	14,2	0,14	Muddy detrital
13	17,9	17,4	41,9	22,8	0,17	Muddy detrital
14	*	10,2	85,5	4,3	0,14	Mud
15	*	4,3	92,8	2,9	0,12	Mud
16	*	57,1	22,2	20,7	0,09	Muddy sand
17	*	54	32	14	0,07	Muddy sand
18	*	39,8	49,1	11,1	0,1	Sandy mud
19	*	50,2	37,1	12,7	0,08	Muddy sand
20	*	77,6	14	8,4	0,05	Sandy mud

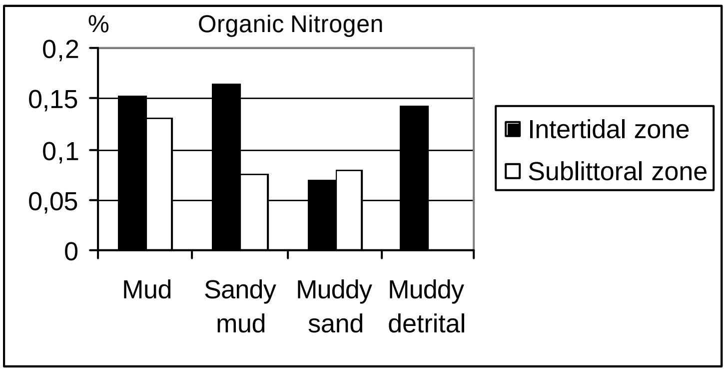

Fig. 4 - Organic Nitrogen in the different sedimentary groups.

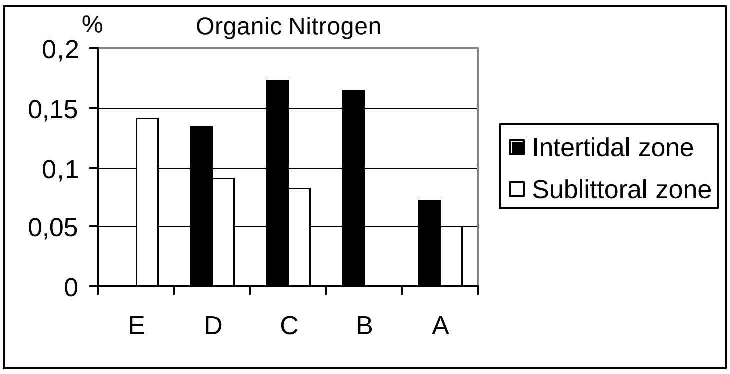

Fig. 5 - Organic Nitrogen variation along the estuary.

Faunal richness

During the sampling period, 66,2% of the species were identified from the sublittoral zone and 33,8% from the intertidal zone (Table 2), which were divided in the main zoological groups as follows:

Intertidal zone - Polychaetes (37,5%); Crustaceans (29,2%); Molluscs (25,0%); Others (8,3%).

Sublittoral zone - Polychaetes (57,5%); Crustaceans (12,8%); Molluscs (21,3%); Others (8,4%).

The polychaetes and the molluscs exhibited their higher species richness values in the Polyhaline sector of the estuary (*NO* = 24 and *NO* = 7 respectively), while the number of crustacean species was higher in the central zone (C sector) (*NO* = 7).

A dominance of the deposit-feeding species (47,8%) was observed in the whole estuary, particulary in its Mesohaline sector. Together with omnivorons species (30,3%), they represented the majority of species identified from the intertidal zone. They were followed by the suspension-feeding species (13,5%) and the carnivores (7,1%), which were more frequent in the Polyhaline sector. The few herbivorous species identified (0,6%) were observed in the central zone of the estuary (C and D sectors).

Based on the various sedimentary biotopes in the inventory, the oyster-beds and the sublittoral muds sediments, were the ones which exhibited the highest species richness values. In the sandy muds they were reduced (Fig. 6). These values decreased along the estuary, from the mouth to the upstream areas (Fig. 7). As for seasonal variation, the highest species richness values were observed in Spring and Summer.

As to the specie's frequency of ocurrence, in relation to biotopes and salinity sectors of the estuary, the most characteristic species (with steadiness and fidelity values highter to 75%), were determined as follows:

Nereis (Hediste) diversicolor - frequent in the muddy areas of the Mesohaline and Polyhaline sectors.

Lanice conchilega - very common in the sublittoral muds of the Polyhaline sector.

Scrobicularia plana - very common in the mud flats of the Mesohaline and Polyhaline sectors.

Cyathura carinata - frequent in the oyster-beds, and common in the mud flats. Very common in the Polyhaline sector.

Carcinus maenas - frequent in the oyster-beds, and very common in the sublittoral muds. Very common in both saline sectors.

Sphaeroma monodi - common in the oyster-beds of the Mesohaline and Polyhaline sectors.

Nereis (Neanthes) succinea - exclusive and very common to the oyster-beds. Frequent in the Polyhaline sector.

Corophium volutator - common in muddy sand flats. Frequent in the Mesohaline sector.

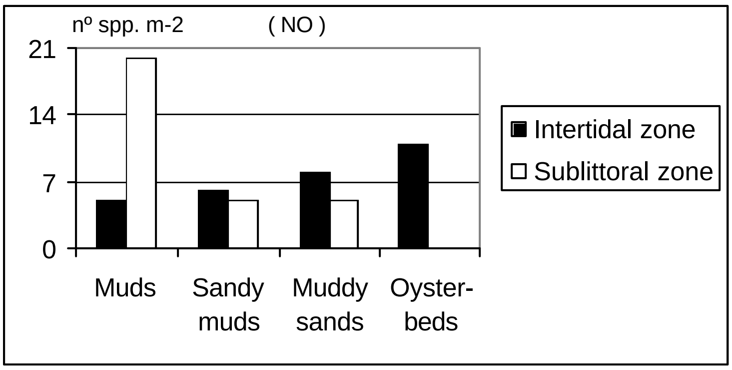

Fig. 6 - Species richness distribution relative to the sedimentary groups.

TABLE 2 - List of species collected at the intertidad and subllitoral zones of the Tagus estuary. (A = Sand; AV = Muddy sand; VA = Sandy mud; V = Mud; O = Oyster bed; SD = Rigid substract.

TAGUS ESTUARY			
Species		**Intertidal zone**	**Sublittoral zone**
		Type of sediment	
Cnidarians			
Cereus pedunculatus	(Pennant)		(VA)(AV)
Nemerteans n. id.			(VA)(V)
Sipunculans n. id.			(VA)(V)
Oligochaetes			
Lumbricidae n .id.		(A)(AV)	
Tubificidae n. id.		(AV)(VA)(V)(O)	(AV)(VA)
Polychaetes			
Autolytus cf aurantiacus	(Claparède)		(VA)
Boccardia redeki	(Horst)	(O)	
Capitella capitata	(Fabricius		(V)(VA)
Diopatra neapolitana	Delle Chiaje		(VA)
Eunereis longissima	(Johnston)		(V)
Eunoe nodosa	(Sars)		(VA)(V)
Glycera Rouxii	(Audouin & Edwards)		(VA)
Glycera trydactila	(Schmarda)	(V)(VA)	(V)(VA)
Harmothoe cf spinifera	Ehlers		(VA)
Heterocirrus bioculatus	(Keferstein)		(VA)
Heteromastus filiformis	Claparède		(VA)
Lagis koreni	Malmgren		(VA)
Lanice conchylega	(Pallas)		(VA)
Lepidonotus clava	(Montagu)		(VA)
Leptonereis glauca	Claparède		(VA)
Marphysa sanguinea	(Montagu)	(O)	(VA)
Mellina palmata	(Grube)		(VA)
Mysta picta	(Quatrefages)		(V)
Nephthys hombergi	(Audouin & Edwards)	(VA)	(VA)
Nereis (Hediste) diversicolor	Muller	(O)(V)(VA)(AV)	(VA)
Nereis (Neanthes) succinea	(Leuckart)	(O)	

(Cont. **TABLE 1**)

TAGUS ESTUARY

Species		**Intertidal zone**	**Sublittoral zone**
		Type of sediment	
Crustaceans			
Atylus swammerdami	(Milne-Edwards)		(VA)
Balanus sp.		(O)	(O)
Carcinus maenas	(Linnaeus)	(O)(VA)	(VA)(V)
Corophium volutator	(Pall)	(AV)	
Cyathura carinata	(Kroyer)	(V)(VA)	
Gammarus chevreuxi	Sexton	(AV)	(AV)
Leptocheirus pilosus	Zaddach	(O)	
Melita palmata	(Montagu)	(O)(VA)	
Sphaeroma monodi	Bocquet,Hoestlandt & Levi	(O)	
Zenobiana prismatica	(Risso)		(V)
Molluscs			
Barnea candida	(Linnaeus)		(VA)(V)
Cerastoderma edule	(Linnaeus)	(O)	(AV)
Corbicula sp.		(AV)	(AV)(VA)
Crassostrea angulata	(lamarck)	(O)	
Hinia sp.			(VA)(V)
Hydrobia ulvae	Pennant	(O)	
Montacuta ferruginosa	(Montagu)		(VA)(V)
Mytilus galloprovincialis	Lamarck	(O)	
Nucula nucleus	(Linnaeus)		(VA)
Pholas sp.			(VA)(V)
Rissoa sp.			(VA)
Scrobicularia plana	(Da Costa)		(VA)(V)
Tellina sp.			(A)
Venerupis sp.			(V)(VA)

Faunal abundance

During the sampling period 13544 individuals were identified and around 75% of them were observed in the intertidal zone. The sublittoral zone showed high abundances only towards the estuary mouth (stations 14 and 15) due to high density of the polychaetes *Nereis (Hediste) diversicolor* (D = 1282) and *Lanice conchilega* (D = 557).

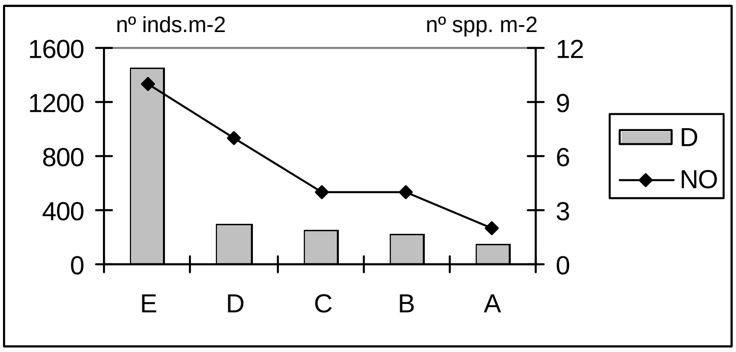

Fig. 7 - Variation in species richness (NO) and density (D) along the estuary.

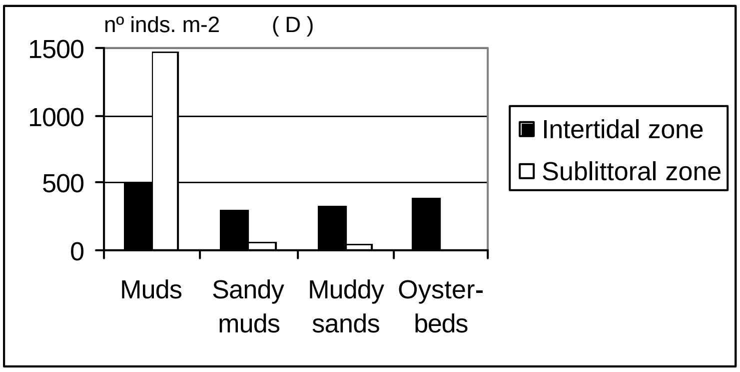

Fig. 8 - Density distribution relative to the sedimentary groups.

Polychaetes represented 77% of the total abundance. *Nereis (Hediste) diversicolor* (45,7%) is the most frequent species in the intertidal zone, as well as in the sublittoral zone at the estuary mouth. This group was very characteristic in the Polyhaline sector of the estuary (E sector) (N = 581).

The crustaceans (13,0%), in the majority *Corophium volutator* (7,3%) and *Cyathura carinata* (3,2%), were more abundant and common in the intertidal zone of the Mesohaline sector (A and B sectors) (N = 160 and N = 81, respectively).

Among the molluscs (5,0%), the bivalve *Scrobicularia plana* (3,0%), was the most abundant species and particulary in the intertidal muddy and sandy mud sediments. This group was better represented in sectors C and E (N = 46 and N = 18, respectively).

Within the sediment biotopes, the highest densities were found in the muds group, both in the intertidal zone (D = 488) and in the sublittoral zone (D = 469). The mud communities in the estuary mouth, with *Nereis (Hediste) diversicolor* and *Lanice* *conchilega,* showed on an average the highest densities (*D* = 1174). They were followed by the oyster-beds (*D* = 318) and the muddy sand communities with *Corophium volutator* (*D* = 259) (Fig. 8).

In parallel with the species richness, the mean density values also decreased upstream along the estuary, from E sector to A sector (Fig. 7).

In terms of season, the highest mean density values were observed in the Spring and Summer periods.

Species diversity and evenness

Globally, the calculated species diversity and evenness values were very low. The mean values were relatively similar in the intertidal and sublittoral zones.

The highest species diversity values were observed in the intertidal oyster-beds (*H'* = 1,26) and in sublittoral muds with *Lanice conchilega* of the estuary mouth (*H'* = 1,31). The lowest values were registered in the sandy and muddy groups, particulary upstream in the estuary, in the sandy mud communities (*H'* = 0,30) (Fig. 9).

With regard to evenness, the most significant values were also registered in the oyster-beds (*J'* = 0,68) and in the sedimentary sandy mud groups (*J'* = 0,44). The least significant values were observed in the intertidal compact muds (*J'* = 0,29). The fact that the oyster-beds present higher evenness values, might suggest the presence of better structured communities (Fig.10).

Along the salinity gradient, the mean value of these descriptors decreased from the estuary mouth to upstream (Fig. 11), while the species dominance value increased in the same direction.

With regard to seasons these values were lower during the Autumn and Winter periods (*H'* = 0,61; *J'* = 0,37).

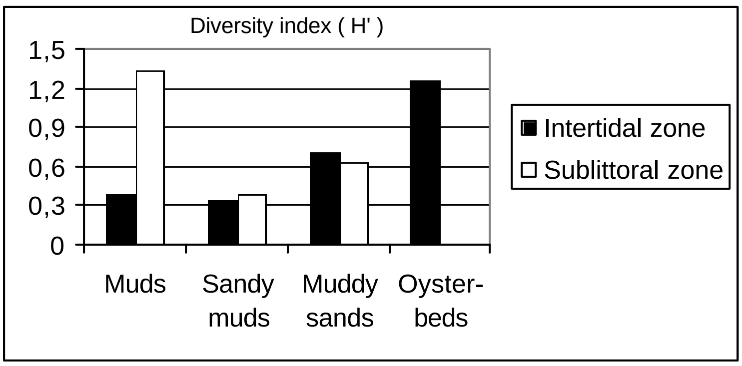

Fig. 9 - Species diversity relative to sediment type.

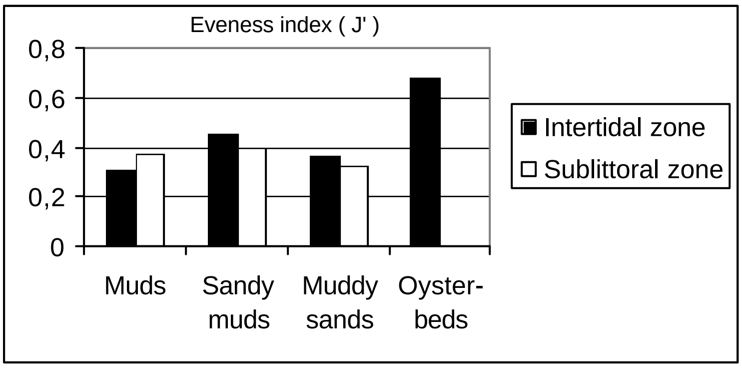

Fig. 10 - Eveness' distribution relative to sediment type.

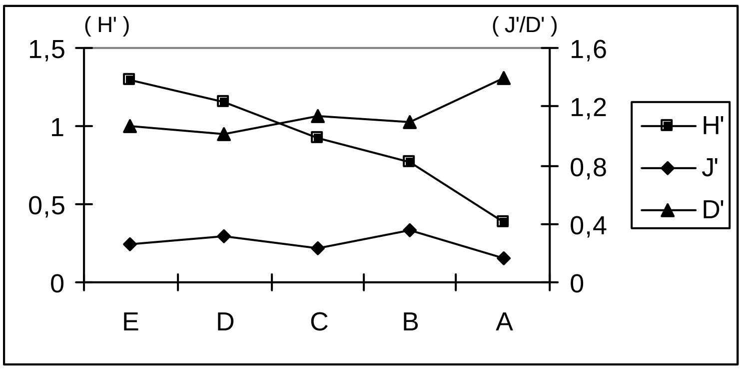

Fig. 11 - Distribution of the species diversity (H'), eveness (J') and dominance (D') along the estuary.

Biomass

A correlation was observed between the biomass values and density distribution. A mean biomass value of about 1,5 g. m^{-2} was estimated for the estuary, which corresponds to a mean density of 403 inds. m^{-2}.

About 64% of the total biomass was observed in the sublittoral zone. Because the polychaetes dominated the intertidal and sublittoral zones, representing 71% of the total biomass. They were followed by the crustaceans (20,3%), the molluscs (8,3%) and Others (0,7%).

From the various biotopes, and in parallel with the distribution of the densities, the sublittoral muds with *Lanice conchilega* (*B* = 7,05; *D* = 1389) and oyster-beds

(*B* = 2,46; *D* = 326) were the communities that showed the highest values in terms of biomass and density (Fig. 12).

The biomass variation along the estuary was identical to other demographic parameters, with a decline in its value from the estuary mouth upstream. About 85% of the estimated biomass of the estuary was shared by Polyhaline zone (Fig. 13). The polychaetes were observed at their highest densities and biomass in D sector (*B* = 5,7; *D* = 691), due essentially to the strong presence of *Lanice conchilega* and *Nereis (Hediste) diversicolor.* Although the crustaceans exhibited their highest densities upstream (A and B sectors), due to the presence of *Corophium volutator,* the highest biomass value was registered in D sector (*B* = 1,05), due to the presence of *Carcinus maenas* in the oyster-beds, which occupy vast intertidal areas in this sector. The molluscs (*B* = 0,61) and Others (*B* = 0,07) showed their highest average biomass values in E sector (Fig. 14). In terms of season, the highest average biomass values were registered during the Autumn period (*B* = 2,03).

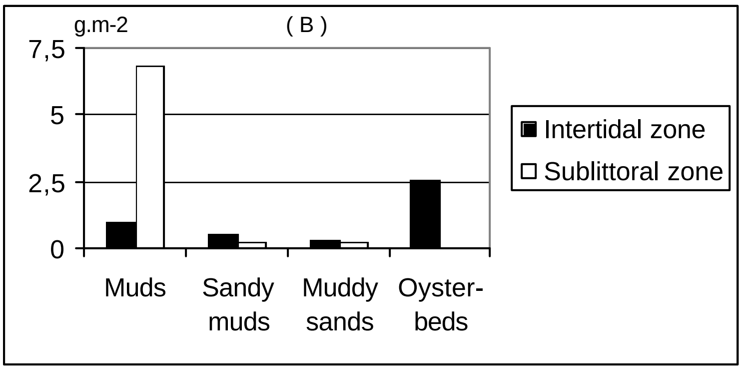

Fig. 12 - Biomass distribution relative to the sedimentary groups.

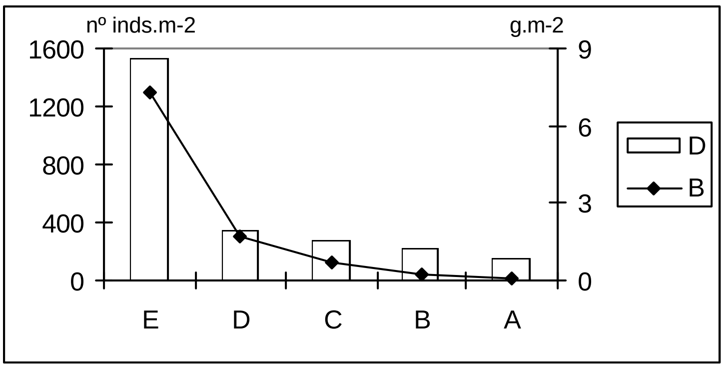

Fig. 13 - Change in density (D) and biomass (B) along the estuary.

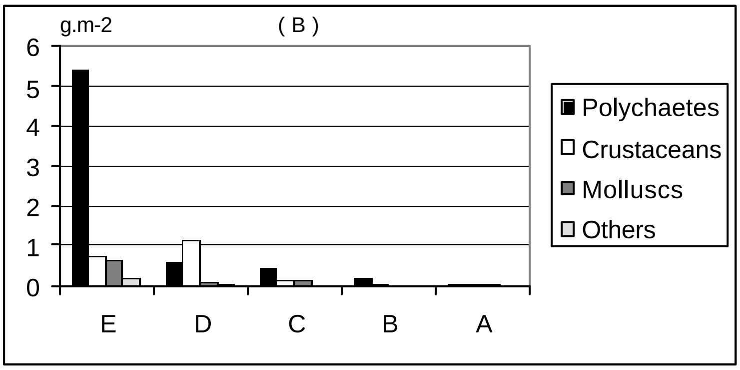

Fig. 14 - Zoological groups biomass along the estuary.

DISCUSSION

The Tagus estuary is subjected to a fast tides because of its hydrographic regime. Due to it's particular morphological and hydrographic characteristics it verifies a high area/volume ratio, especially in mid estuary, and very intense dynamics on the semidiurnal tide.

The sedimentological studies show that there is a greater deposit of silto-argillaceous in the upstream areas, and some preferential areas of erosion and siltation, linked with the intense currents. At the estuary's mouth a deposit of muddy sediments is observed, which is caused by material eroded from the banks, the bottom and comes from the ocean.

The physical and chemical parameters of the estuary present a longitudinal gradient correlated to distance from the mouth (salinity, temperature, dissolved oxygen), and a vertical gradient related to the tidal range, currents and depth, which are involved in its bottom sedimentary characteristics (granulometry, organic matter, interstitial water) (confinement).

The fauna appears to be typical of a muddy estuary with a large input of freshwater which will limit the benthos on the upper and middle estuary. The reduction of fauna in these areas appears to be a consistent with a lowering of salinity and with the hidrographic system. The hydrological and sedimentological parameters affect the presence (or eliminate) of certain species in the various communities, and interfere with both their longitudinal and vertical distribution. This is translated into a decrease in species richness, abundance, biomass, species diversity and evenness, along the estuary (from the mouth to upstream), and an increase in species dominance in the same direction.

The soft sublittoral substrate within the estuary showed also a very sharp decline in both the number of species and individuals which are present in the bottom. The poverty of the fauna in the center of the estuary is a reality, with a reduction of the species richness and the densities in sublittoral zone. The possibility that hydro-sedimentary system is affecting the fauna cannot be regarded.

The study showed that the sectors A and B are characterized by fresh-water and euryhaline species. Downstream from these sectors, in the central part of the estuary (C and D sectors) which show a marine influence, the number of euryhaline species is greater. The estuary's mouth (E sector) is influenced by the coastal waters, and the benthic communities are characteristic of the corresponding sediment and salinity regime. This is a transition to the marine communities. The fauna is diverse and characteristic of high salinity. Roughly 30 species have been found in the sublittoral muds. The most abundant were the polychaetes *Lanice conchilega, Nereis (Hediste) diversicolor, Nephthys hombergi* and the mollusc *Barnea candida.*

CONCLUSION

The estuary appears to be a large fresh water input system which, associated with the hydro-sedimentary complex, strongly limits the species diversity of the communities, particulary in the upstream sublittoral zones (Mesohaline sector). Together with seasonal variation in salinity, to which the estuary is subject, they result in situations of continual stress which are reflected on structure of the benthic communities. Therefore, the low diversities observed, are a consequence of the fact that the majority of these communities showed strong dynamics, and are dominated by 2 or 3 characteristic species. The fact that the oyster-beds and the sublittoral muds with *Lanice conchilega* show higher evenness values, might suggest the presence of better structured communities.

The benthic communities within the estuary show a typical *Nereis (Hediste) diversicolor* - *Scrobicularia plana* - *Cyathura carinata* association, very common in the intertidal muddy substratum of the estuarine zone (5 - 25‰). In sectors C and D, the oyster-beds are responsible for the presence of *Nereis (Neanthes) succinea, Melita palmata, Marphysa sanguinea* and *Sphaeroma monodi.*

With season, these communities reflect the influence of the Oligohaline and Marine domains, particulary in the transition zones (A and D sectors), forming a sort of "continuum" between them. Upstream, in the transition to the Oligohaline communities (A sector), other groups of species are associated with the preceding ones, *Gammarus chevreuxi, Corbicula* sp. and *Corophium volutator,* species that can be observed downstream in winter time, following the salinity's dynamics. In the estuary's terminal zone species more marine affinity are present (*Lanice conchilega, Nephthys hombergi, Barnea candida*), functioning the sector E as the transition to the Marine communities. This whole group of species defines the presence of an Atlantic euryaline-eurythermic biocenosis, which appears to correspond to the community described by WOLFF (1973) for European estuaries.

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