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Fish assemblage dynamics in the Tagus and Sado estuaries (Portugal)

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Abstract: From May 2001 to April 2002 the ichthyofauna from Tagus and Sado estuary was monthly sampled. 25 species from 18 families were identified in Tagus samples, and 38 species from 21 families in Sado estuary. Only 14 species (26%) occurred in the two estuaries, but 14 families (58%) were common for both. *Pomatoschistus minutus*, *Gobius niger*, *Syngnathus* sp and *Sardina pilchardus* were the dominant species in Tagus estuary. *Gobius niger*, *Monochirus hispidus, Halobatrachus didactylus*, *Arnoglossus laterna* and *Diplodus bellottii* were the dominant species in Sado. From CCA analysis a separation of Tagus samples from those of Sado is evident. Furthermore, in Sado estuary a spatial pattern is evident, while in Tagus estuary no pattern is evident among sampling areas or seasons. The physical factors which have a major influence are salinity, total organic mater and percentage of mud, being the last two highly related. Comparing the diversity index in the two estuaries the values are higher in Sado estuary probably due to a greater influence of seawater and a higher variability of sediment, which induce to a more rich community.

Résumé : *Dynamique des assemblages de poissons dans les estuaires du Tage et du Sado (Portugal).* La faune ichthyologique des estuaires du Tage et du Sado a été échantillonnée mensuellement depuis le mois de mai 2001 jusqu'au mois d'avril 2002. On a identifié 25 espèces de 18 familles dans le Tage et 38 espèces de 21 familles dans le Sado. Seules 14 espèces (26%) sont communes aux deux estuaires ; 14 familles (58%) sont communes. Les espèces dominantes du Tage sont *Pomatoschistus minutus*, *Gobius niger*, *Syngnathus* sp et *Sardina pilchardus* et dans le Sado se détachent *Gobius niger*, *Monochirus hispidus, Halobatrachus didactylus*, *Arnoglossus laterna* et *Diplodus bellottii*. L'analyse canonique des correspondances a montré une séparation nette entre les échantillons du Tage et ceux du Sado. En outre, une structure spatiale est visible dans l'estuaire du Sado, alors qu'aucune structure, ni spatiale ni saisonnière, n'apparaît pour le Tage. Les facteurs physiques les plus influents sont la salinité, la matière organique totale et le pourcentage de vase, ces deux derniers se trouvant fortement corrélés.

Keywords: Fish assemblage ● Environmental factors ● Estuarine system ● Tagus ● Sado ● Portugal

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Introduction

Estuaries have long been known to be important as nurseries areas, migration routes and habitats for estuarine residents (Haedrich, 1983). They are also very important for human activities, and often associated to large urban or industrial areas. Along with anthropogenic pressures (e.g. poldering and land-claim, channel management, power stations and water abstraction, barrages) (Cattrijsse et al., 2002), estuaries are affected by natural changes in environmental condition. Temperature and salinity gradients, alterations of water-column turbidity and in chemical composition including changes in nutrients, dissolved gases and trace metals are, among others factors, prominent features of estuarine systems likely to affect fish populations (Elliott & McLusky, 2002).

Fish have very diverse live history strategies and occupy a variety of ecological niches using the estuary in several different forms. Some species have obligate live history stages in the estuary such as estuarine resident or diadromous fishes, others are facultative users (marine or freshwater opportunists) and others only occasionally find their way into an estuary (marine vagrants) (Able, 2005).

The rivers Tagus and Sado form two of the major estuarine systems in the Atlantic coast of the Iberian Peninsula (Costa, 1988; Cunha, 1994). Both estuaries suffer the influences of industrial complexes, farming, urban areas and fishing (Cabral, 1998), activities that are often linked with alterations of the health status and ecological integrity of estuaries. Over two million people live in the area of influence of the Tagus estuary and over 300 000 people live around Sado estuary.

Because estuaries are water-bodies sensitive to the adverse effects of human impacts (Elliott & McLusky, 2002) it is of major importance to investigate the nature of estuarine communities to aid preservation and management of these areas (Elliott, 2002).

The aim of the present study is two-fold: 1) to identify the main patterns of spatial and temporal variation in the fish assemblage of each estuary, and 2) to describe the environmental conditions associated with the fish biota.

Material and Methods

Study areas

Tagus estuary has an area of 325 km^2 of which 40% is intertidal area (Cabral, 1998) and a tidal range of 4.6 m with a mean depth less than 10 m (França et al., 2005). The mean Tagus river flow is 400 m^3 s^{-1}, being highly variable both seasonally and interannually (França et al., 2005). Beyond the Tagus, 15 tributaries contribute to the import of freshwater into the estuary.

Sado estuary has an area of approximately 180 km^2 of which 44% is intertidal (Vasconcelos et al., 2007). The river flow regime presents significant interannual and seasonal variations and is highly dependent on the amount of rain occurring in the south part of Portugal, varying from 1 m^3 s^{-1} in summer to 60 m^3 s^{-1} in winter (Martins et al., 2001). Only 5 small tributaries provide freshwater to the estuary and, consequently, the estuary has a high salinity, above 29.5, all over the year (Cunha, 1994). The tidal regime in the area is primarily semidiurnal with a range of 0.6 to1.5 m in neap tides and of 1.6 to 3.5 m in spring tides (Martins et al., 2001; Amaral & Cabral, 2004).

Sampling procedures

From May 2001 to April 2002, 4 sites in the Tagus and 5 sites in the Sado estuary were sampled monthly (Fig. 1), using a 4-m beam trawl with 10-mm mesh size. This gear is one of the more appropriate to the estuarine environment (Potts & Reay, 1987) due to its reduced selectivity when compared to other gears. Trawls were towed for 15 min at 1.85 km h^{-1}, during daylight and low water of spring tides. After capture, specimens were kept at low temperature in an icebox and later identified, measured to the nearest mm (total length, TL) and weighed to the nearest 0.01 g (wet weight, WW) in the laboratory. The identification was conducted according to Whitehead et al. (1986).

During all samplings, temperature (± 0.1ºC), salinity (± 0.1) and dissolved oxygen concentration, DO (± 0.1 mg l^{-1}) were measured using a multiparameter water quality probe (YSI, model 85). In spring (May), summer (August), autumn (November) and winter (February), sediment samples were collected using a van Veen grab and analysed for granulometric purposes. These samples were washed to remove the fine portion (< 0.063 mm), dried at 70ºC and then sorted in a 1-mm sieve to separate gravel from sand. The organic matter in the sediment was also determined by the loss of weight on ignition at 450ºC for two hours. Species were grouped into ecological guilds according to common traits of life history, biology and/or behaviour (see Elliott & Dewailly, 1995).

Data analysis

For data analysis, months were grouped in seasons: March, April, May (spring); June, July, August (summer); September, October, November (autumn); December, January, February (winter). *k*-dominance curves (Lambshead et al., 1983) were used to graphically account for diversity outline. For each sampling site, the species richness (Margalef, 1958), the Shannon-Wiener diversity index (Shannon & Weaver, 1949) and the evenness index (Pielou, 1977) were used to characterize fish temporal and spatial abundance. Significant differences on the abiotic

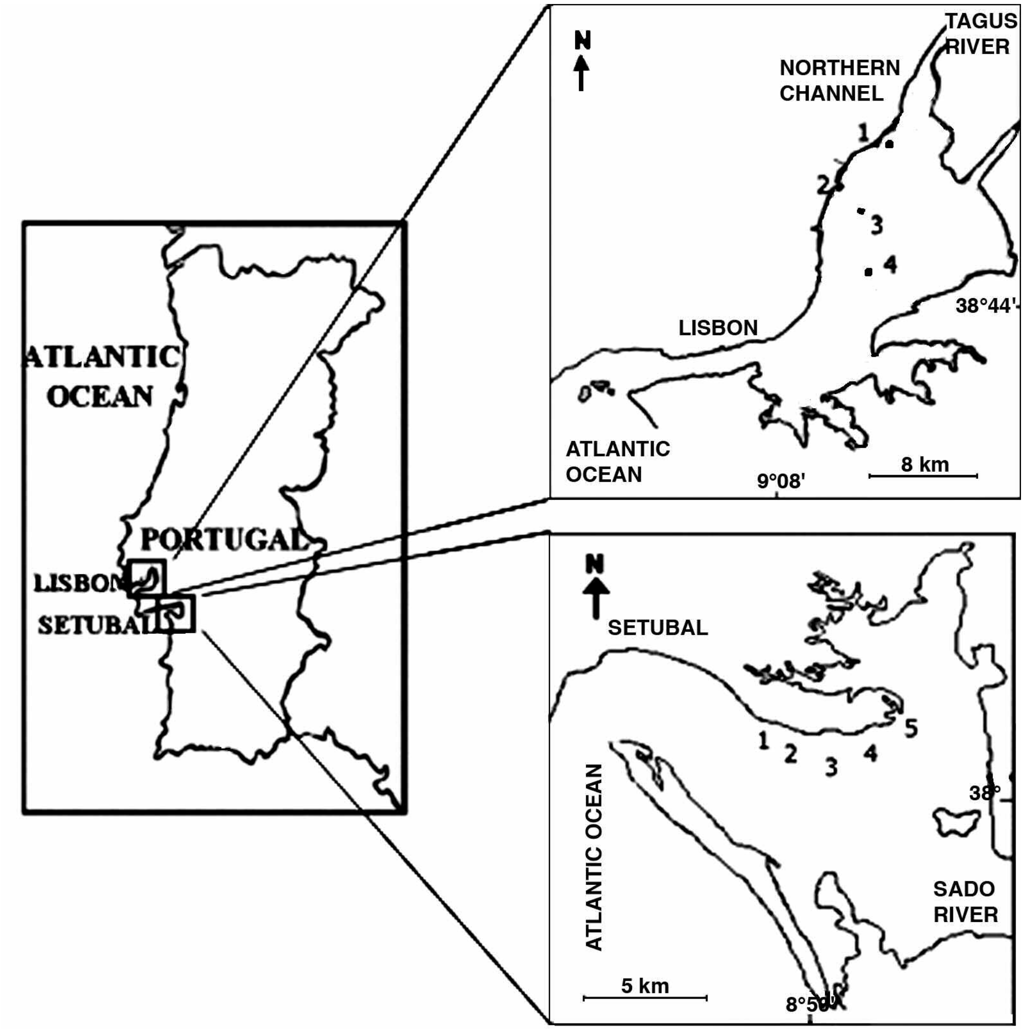


Figure 1. Map of the sampling sites in Tagus and Sado estuaries.
Figure 1. Localisation des points d'échantillonnage aux estuaires du Tage et du Sado.

parameters and ecological indices were evaluated among sites and seasons (Kruskal-Wallis test) and estuaries (Mann-Whitney test) for a significant level (α) of 0.05 (Zar, 1999).

Fish (excluding the species with abundance lower than 1%) and environmental data matrix were submitted to canonical correspondence analysis (CCA) in order to obtain a direct environmental interpretation of the extracted ordination axes (Ter Braak, 1994). Despite the fact that CCA is a linear technique, it is less susceptible than other ordination methods to non-linearities in the data matrix, because it explicitly assumes non-linear responses of species along environmental gradients (McGarigal et al., 2000). CCA was performed using CANOCO 4.5 (Ter Braak & Smilauer, 1998).

Results

Abiotic parameters

Mean values of temperature and dissolved oxygen were not significantly different between estuaries ($U = 0.242$, $p = 0.809$, $U = 1.691$, $p = 0.091$ respectively). Mean salinity values were significantly higher (always above 30) in Sado estuary ($U = -8.7888$, $p < 0.001$), while in Tagus estuary the values varied between 10.3 and 28.3 (Fig. 2).

Seasonally, Tagus estuary presented significant differences in temperature and salinity (Table 1) varying the former from a mean value of 13ºC in winter to 22ºC in summer. The latter varied from a mean value of 17 in spring to 24 in summer. Sado estuary presented significant

Table 1. Values of the Kruskal-Wallis test for the physical parameters. Significant values (α < 0.05) are signed with *.
Tableau 1. Résultats du test de Kruskal-Wallis sur les paramètres physiques. Les valeurs significatives (α < 0,05) sont signalés par *.

	Among Seasons				Among Sites			
	Tagus		Sado		Tagus		Sado	
	Kruskal-Wallis Test H	p value	Kruskal-Wallis test H	p value	Kruskal-Wallis test H	p value	Kruskal-Wallis test H	p value
Temperature	32.9539	< 0.001*	32.6006	< 0.001*	0.3304	0.9542	0.2945	0.9902
Salinity	9.9456	0.0190*	14.5103	0.0023*	19.8265	< 0.001*	8.3110	0.0808
Dissolved Oxygen	1.4130	0.7025	13.0051	0.0046*	6.6385	0.0844	2.5963	0.6275

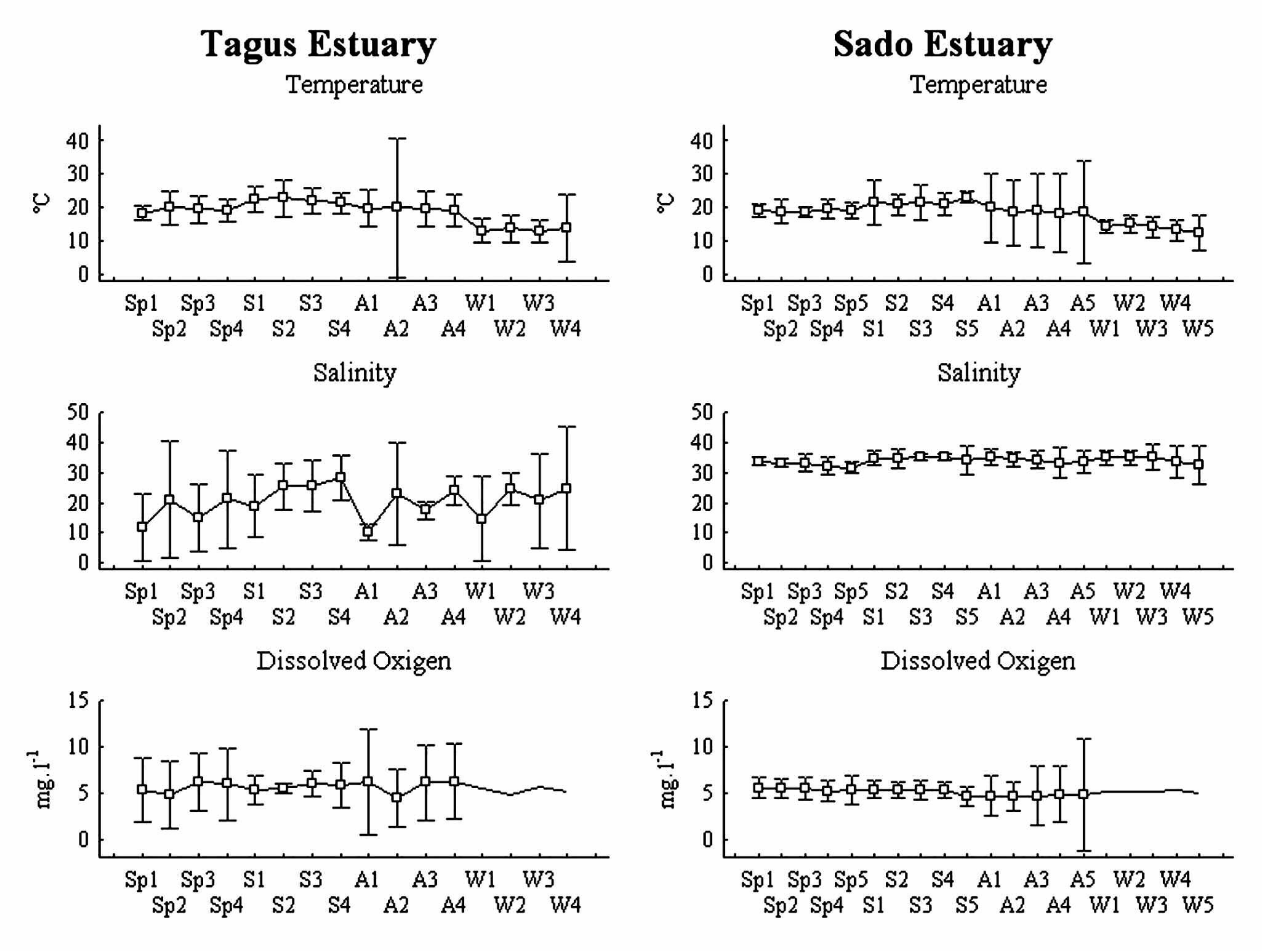


Figure 2. Mean values recorded for temperature, salinity and dissolved oxygen during spring, summer, autumn and winter in the Tagus and Sado estuaries.
Figure 2. Valeurs moyennes enregistrées aux estuaires du Tage et du Sado pour la température, la salinité et l'oxygène dissous pendant le printemps, l'été, l'automne et l'hiver.

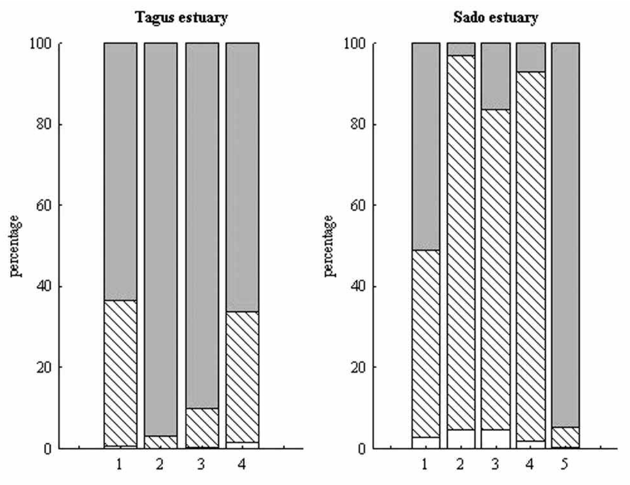


Figure 3. Sediment composition in the sampling areas of Tagus and Sado estuary (gravel - white bar; sand - striped bar; mud - grey bar).

Figure 3. Composition du sédiment aux stations d'échantillonnage des estuaires du Tage et du Sado (gravier - colonne blanche ; sable - colonne rayée ; vase - colonne grise).

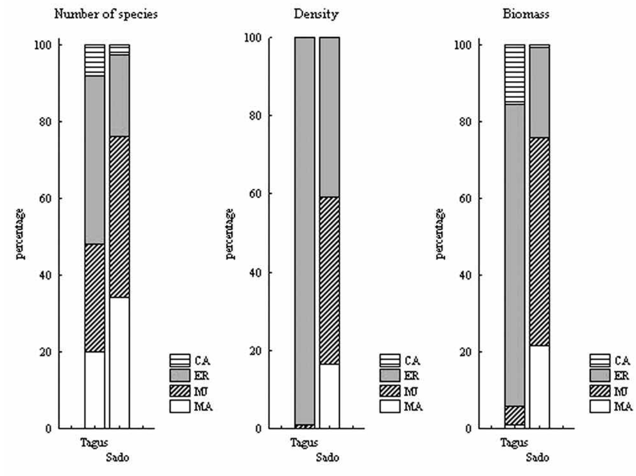


Figure 4. The relative presence of ecological guilds in the Tagus and Sado estuaries. CA - catadromous species; MA - marine adventitious species; MJ - marine juveniles; ER - estuarine residents.

Figure 4. Présence relative des différents catégories écologiques aux estuaires du Tage et du Sado (CA - espèces catadromes ; MA - espèces marines occasionnelles ; MJ - juvéniles d'espèces marines ; ER - espèces résidant dans l'estuaire).

differences for all the physical parameters (Table 1). Temperature varied from a mean value of 13ºC (winter) to 21ºC (summer), salinity varied from a mean value 32 (spring) to 35 (summer) and dissolved oxygen from a mean value of 4.6 mg l^{-1} (autumn) to 5.5 mg l^{-1} (spring) (Fig. 2).

Spatially, in Tagus estuary, there were significant differences (Table 1) in salinity values among sites (mean values varying from 13.9 in site 1 to 24.5 in site 4). On the contrary no significant differences among sites (Table 1) were observed in the temperature and dissolved oxygen (Fig. 2). In the Sado estuary, no significant differences in the abiotic parameters were recorded (Table 1).

Sediment composition in the Tagus estuary is principally mud across all sampling sites, reaching very high values (> 90%) in sites 2 and 3 (Fig. 3). In contrast, sand dominated the sediment composition of the Sado estuary sampling sites, especially in samples 2, 3 and 4 (> 80% sand). Gravel-sized particles were almost nonexistent in sampling sites within the Tagus, but represented a percentage close to 4% across the Sado estuary (Fig. 3).

Assemblage Structure

In the Tagus estuary, 2976 individuals weighing a total of 17.7 kg were captured from 48 trawls. These specimens belonged to 25 species (1 elasmobranch and 24 teleost species) within 18 families (Table 2). In the Sado estuary, 2310 specimens comprised of 3 elasmobranch (3 families) and 35 teleost species (18 families) were caught in 60 trawls (Table 2), weighing a total of 40.2 kg. Fourteen species (29%) from 11 families (44%) occurred in the two estuaries. Eleven species appeared exclusively in the Tagus estuary while 24 were exclusive for Sado estuary (Table 2).

Sand goby *Pomatoschistus minutus* (Pallas, 1770) dominated the Tagus estuary assemblage with a density close to 93%, representing a biomass of 17.5%. The toadfish *Halobatrachus didactylus* (Schneider, 1801) attained the highest biomass (48%) in Tagus estuary. In the Sado estuary, the black goby *Gobius niger* (Linnaeus, 1758) presented the highest density (22.6%) followed by the Senegal seabream *Diplodus bellottii* (Steindachner, 1882) (14.8%) and scaldfish *Arnoglossus laterna* (Walbaum, 1792) (13.5%). The highest biomass was recorded by *D. bellotti* (19.4%), the sole *Solea solea* (Linnaeus, 1758) (17.2%) and *H. didactylus* (17.0 %).

According to the definitions in Elliott & McLusky (2002) only four ecological guilds could be found in both estuaries (Table 3). Freshwater species and the marine seasonal migrants were not found in this one-year sample. The relative proportion of each guild varied between the two estuaries (Fig. 4). Resident species were dominant in all aspects (number of species, density and biomass) in Tagus estuary, *P. minutus* being the most important species numerically and *H. didactylus* the most important in biomass.

Table 2. Species composition, ecological guild (EG): CA- catadromous species; MA – marine adventitious species; MJ - marine juveniles; ER - estuarine residents; density (D = ind.1000 m^{-2}) and biomass (B = g.1000 m^{-2}) obtained by season in the Tagus and Sado estuaries.

Tableau 2. Composition des espèces, catégorie écologique (EG): CA - espèces catadromes; MA – espèces marines occasionnelles; MJ - jaunes d'espèces marines ; ER – espèces résidents dans l'estuaire ; densité (D = ind.1000 m^{-2}) et biomasse (B = g.1000 m^{-2}) obtenus pour saison aux estuaires du Tage et du Sado.

		TAGUS ESTUARY								SADO ESTUARY							
		Spring Winter		Summer		Autumn		Winter		Spring		Summer		Autumn			
Family/Species	EG	D	B	D	B	D	B	D	B	D	B	D	B	D	B	D	B
<u>Class Chondrichthyes</u>																	
Fam. Torpedinidae																	
Torpedo torpedo (Linnaeus. 1758)	MA									0.12	47.69						
Fam. Rajidae																	
Raja clavata (Linnaeus. 1758)	MA	0.29	161.21														
Raja undulata Lacepède. 1802	MA											0.20	3.73				
Fam. Myliobatidae																	
Myliobatis aquila (Linnaeus. 1758)	MA									0.12	117.79		693.18				
<u>Class Osteichthyes</u>																	
Fam. Clupeidae																	
Alosa fallax (Lacepède. 1803)	CA											0.18	54.37				
Sardina pilchardus (Walbaum. 1792)	MJ	0.36	2.80	10.40	43.73	4.72	42.51	0.65	7.45			0.56	3.30				
Fam. Engraulidae																	
Engraulis encrasicholus (Linnaeus. 1758)	ER	2.60	10.04	0.19	2.25	2.70	9.41	1.05	4.73	3.77	22.86	30.15	124.01	1.01	6.58	4.13	17.31
Fam. Anguillidae																	
Anguilla anguilla (Linnaeus 1758)	CA	0.02	0.68	0.19	134.33	0.11	264.26	0.29	287.87								
Fam. Congridae																	
Conger conger (Linnaeus. 1758)	MA			0.02	1.59			0.11	2.23	0.23	17.52			0.62	52.37		
Fam. Syngnathidae																	
Hippocampus hippocampus (Linnaeus. 1758)	MA									0.82	4.73	0.33	0.89			0.11	0.22
Hippocampus ramulosus Leach. 1814	MA											0.18	1.17				
Sygnathus sp	ER	0.45	0.64	2.17	2.04	5.79	4.24	1.66	2.48								
Syngnathus typhle (Linnaeus. 1758)	ER									0.25	5.86						
Fam. Gadidae																	
Ciliata mustela (Linnaeus. 1758)	MA					0.10	14.85										
Fam. Serranidae																	
Serranus hepatus (Linnaeus. 1758)	MA															0.12	0.52
Fam. Moronidae																	
Dicentrarchus labrax (Linnaeus. 1758)	MJ	0.10	11.85	0.02	0.56	0.11	6.25	0.19	34.94								
Dicentrarchus punctatus (Bloch. 1792)	MJ											0.09	23.81				
Fam. Carangidae																	
Trachurus trachurus (Linnaeus. 1758)	MJ					0.10	1.15					0.64	6.69	2.23	117.30		
Fam. Sciaenidae																	
Argyrosomus regius (Asso. 1801)	ER	0.29	323.14	0.65	690.85	0.43	662.07	0.10	25.85								
Fam. Sparidae																	
Boops boops (Linnaeus. 1758)	MA	0.10	2.14														
Diplodus sp	MJ																
Diplodus bellottii (Steindachner. 1882)	MJ	0.10	28.76	0.76	66.81	0.81	76.02	0.67	8.50	19.71	746.17	14.12	500.67	3.71	119.79	17.11	747.85
Diplodus sargus (Linnaeus. 1758)	MJ					0.04	1.93			0.10	3.44	0.29	17.05				
Diplodus vulgaris (Geoffroy Saint-Hilaire. 1817)	MJ									0.12	3.43						
Pagrus auriga Valenciennes. 1843	MJ									0.10	0.47						

Sarpa salpa (Linnaeus. 1758)	MA									1.59	35.33	2.15	55.23	0.26	1.93		
Sparus aurata Linnaeus. 1758	MJ									0.10	19.79						
Fam. Labridae																	
Symphodus bailloni (Valenciennes. 1839)	ER	0.12	1.92			1.36	19.47	0.29	6.56	0.30	3.16			1.19	6.20	0.13	4.30
Fam. Gobidae																	
Aphia minuta (Risso. 1810)	ER	0.08	0.26	0.04	0.15	0.14	0.32	2.59	9.38								
Gobius niger Linnaeus. 1758	ER	2.04	46.48	1.52	32.96	2.26	38.91	5.77	123.44	38.61	262.02	25.36	146.44	14.89	80.28	4.61	36.05
Pomatoschistus microps (Krøyer. 1838	ER	30.60	39.85					108.46	228.05			1.12	0.80			0.12	0.04
Pomatoschistus minutus (Pallas. 1770)	ER	4.12	31.42	1059.60	792.09	1215.90	1429.43	485.49	837.80	0.37	0.68					0.24	0.49
Fam. Callionymidae																	
Callionymus lyra Linnaeus. 1758	MA									0.32	3.55	1.65	8.82	3.38	40.11	0.74	18.56
Callionymus reticulatus Valenciennes. 1837	MA									1.19	2.48						
Fam. Blenniidae																	
Parablennius pilicornis (Cuvier. 1829)	MA	0.29	0.21														
Fam. Mugilidae																	
Mugil cephalus Linnaeus. 1758	ER					0.02	38.27										
Liza aurata (Risso. 1810)	MJ	0.10	30.90			0.14	39.46					0.11	39.32	0.44	71.70		
Liza ramado (Risso. 1810)	CA	0.72	751.95	0.17	6.30	0.53	360.92	1.07	925.64								
Fam. Atherinidae																	
Atherina presbyter Cuvier. 1829	ER	0.29	11.00					0.13	1.76	1.13	7.45	0.11	0.46	0.76	3.06	1.11	4.01
Fam. Scorpaenidae																	
Scorpaena notata Rafinesque. 1810	MA															0.13	0.52
Fam. Triglidae																	
Trigla lucerna (Linnaeus. 1758)	MJ									1.84	3.09	0.69	6.69	1.48	117.30		
Trigloporus lastoviza (Brünnich. 1768).	MA											0.11	0.11				
Fam. Bothidae																	
Arnoglossus laterna (Walbaum. 1792)	MJ									12.20	118.78	13.96	283.53	17.73	590.33	5.76	261.17
Arnoglossus thori Kyle. 1913	MJ									1.50	28.14					0.14	2.14
Fam. Soleidae																	
Dicologlossa hexophthalma (Bennett. 1831)	MJ									1.94	23.02			0.24	2.32		
Monochirus hispidus Rafinesque. 1814	MA									17.59	117.79	18.47	693.18	8.95	330.92	1.65	90.06
Solea senegalensis Kaup. 1858	MJ									0.57	64.60	0.29	55.87	0.20	36.00	0.25	22.49
Solea solea (Linnaeus. 1758)	MJ	1.11	62.61	2.25	136.59	0.78	145.96	0.48	115.52	7.97	471.20	8.00	214.90	19.22	972.24	4.30	208.35
Synaptura lusitanica Brito Capello. 1868	MJ									0.10	5.86						
Fam. Batrachoididae																	
Halobatrachus didactylus (Bloch & Schneider. 1801)	ER	2.57	3501.92	5.07	2910.02	1.26	684.13	1.14	1393.82	2.05	84.97	4.44	444.29	13.84	1311.03	0.15	9.27

Marine juveniles dominated Sado estuary, *D. bellottii* being the most representative species in density and biomass. Numerically the resident species were also well represented mainly by *G. niger*.

k-dominance curves for density and biomass (Fig. 5) showed different patterns for Tagus and Sado estuaries. The former showed a high level of dominance mainly in the density, reaching summer and winter 100% at the first species. Sado estuary presented a more even distribution with lower dominance at species level.

Spatial and seasonal pattern

Although the number of species caught in the two estuaries is not statistically different ($U = -1.152$, $p = 0.249$), the comparison of both the diversity and evenness indices showed significant differences ($U = 4.022$, $p < 0.001$, $U = 4.443$ $p < 0.001$, respectively). It must be pointed out that Sado estuary presented the higher values in the diversity indices analysed.

In Tagus estuary, Shannon-Wiener diversity index and evenness varied significantly (Table 4) along the year (with very low values during summer and autumn and higher records in spring and winter) and among sites (sites 3 and 4 being always more diverse). The species richness was similar along the year but significantly different among sites (Table 4). In Sado estuary the diversity index and the species richness varied significantly among seasons (Table 4), having the winter the lowest values (Fig. 6). The evenness was statistically different among sites (Table 4).

The two first axes of the CCA using both species abundance data grouped according to sampling site and season accounted for 38.0% of the total variance and 84.7% of the relationship between abundance

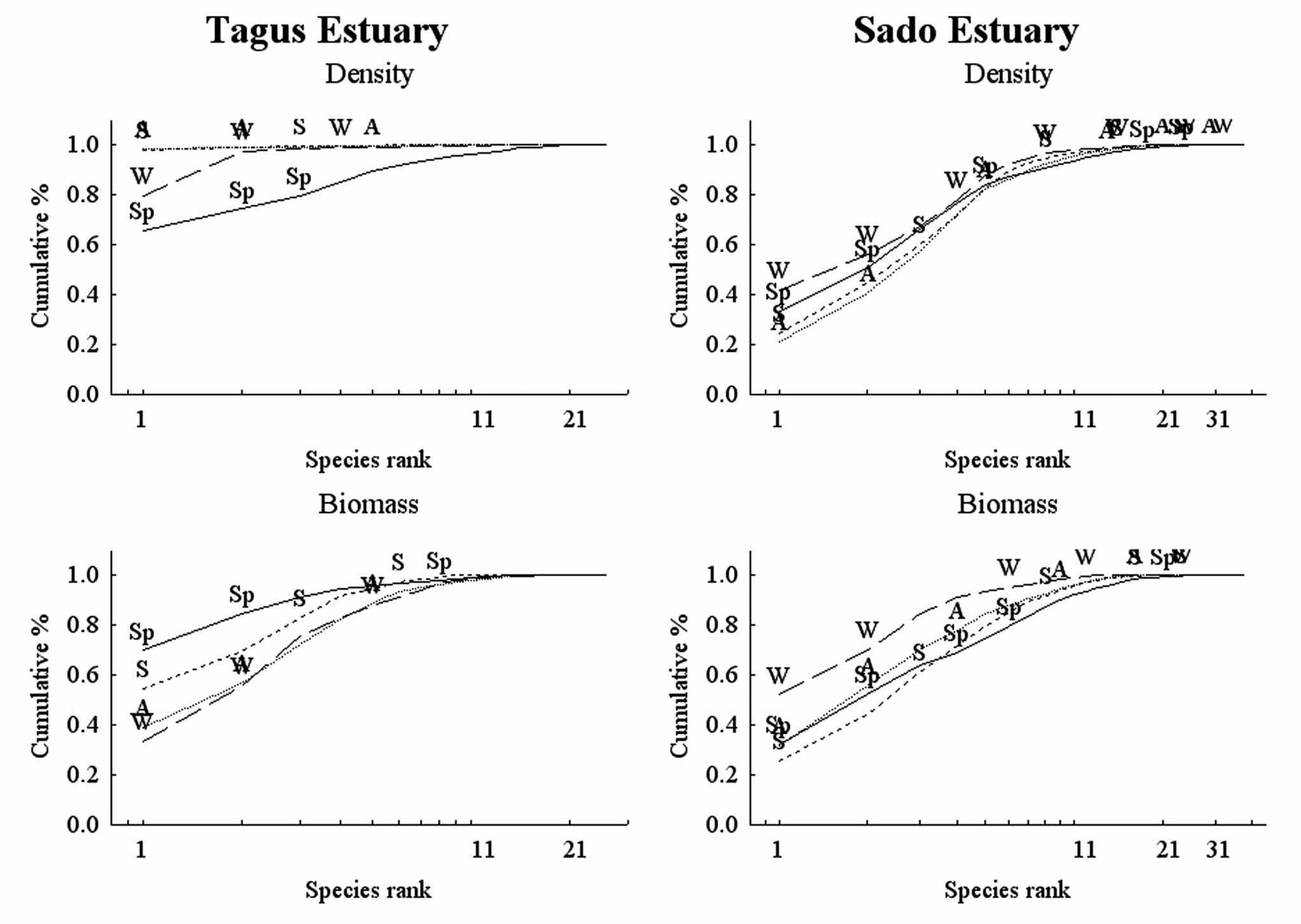


Figure 5. *k*-dominance curves for icthyofauna abundance and biomass in the two estuaries along the four seasons.

Figure 5. Courbes de k-dominance pour l'abondance et la biomasse de la faune ichthyologique au cours de l'année dans les deux estuaires.

Table 3. Density (ind.1000 m^{-2}) and biomass (g.1000 m^{-2}) of fish sampled in Tagus and Sado estuaries grouped by ecological guilds. CA- catadromous species; MA - marine adventitious species; MJ - marine juveniles; ER - estuarine residents.

Tableau 3. Densité (ind.1000 m^{-2}) et biomasse (g.1000 m^{-2}) des poissons échantillonnés aux estuaires du Tage et du Sado agroupés par catégorie écologique (CA - espèces catadromes ; MA - espèces marines occasionnelles ; MJ - jaunes d'espèces marines ; ER - espèces résidant dans l'estuaire).

	Tagus estuary		Sado estuary	
	D	B	D	B
CA	3.10	2731.95	0.18	54.37
MA	0.70	165.24	61.05	2338.40
MJ	23.88	864.30	157.80	5908.79
ET	2948.89	13917.14	149.86	2581.61

and the environmental variables. All sampling areas and seasons related to the Sado estuary clustered separated (in the right edge of the diagram) from those of Tagus estuary (in the left edge) (Fig. 7). Furthermore, in the former estuary, sample areas 1 and 5 were separated from the other sites, being present in the lower and upper parts of the diagram respectively while sites 2 and 3 and 4 overlap in the central area. In the Tagus estuary, no pattern is evident among sampling areas or seasons and all lie in a common group (Fig. 7).

The species distributions show 4 assemblages: two major groups and other two with just a few species present. A first group enclosing the dragonet *Callionymus lyra* Linnaeus, 1758 (CLL), reticulated dragonet *Callionymus reticulatus* Valenciennes, 1837 (CLR), *D. bellottii* (DPB), Senegalese sole *Solea senegalensis* Kaup, 1858 (SLS), ocellated wedge sole *Dicologlossa hexophtalma* (Bennett, 1831) (DLH), white seabream *Diplodus sargus* (Linnaeus,

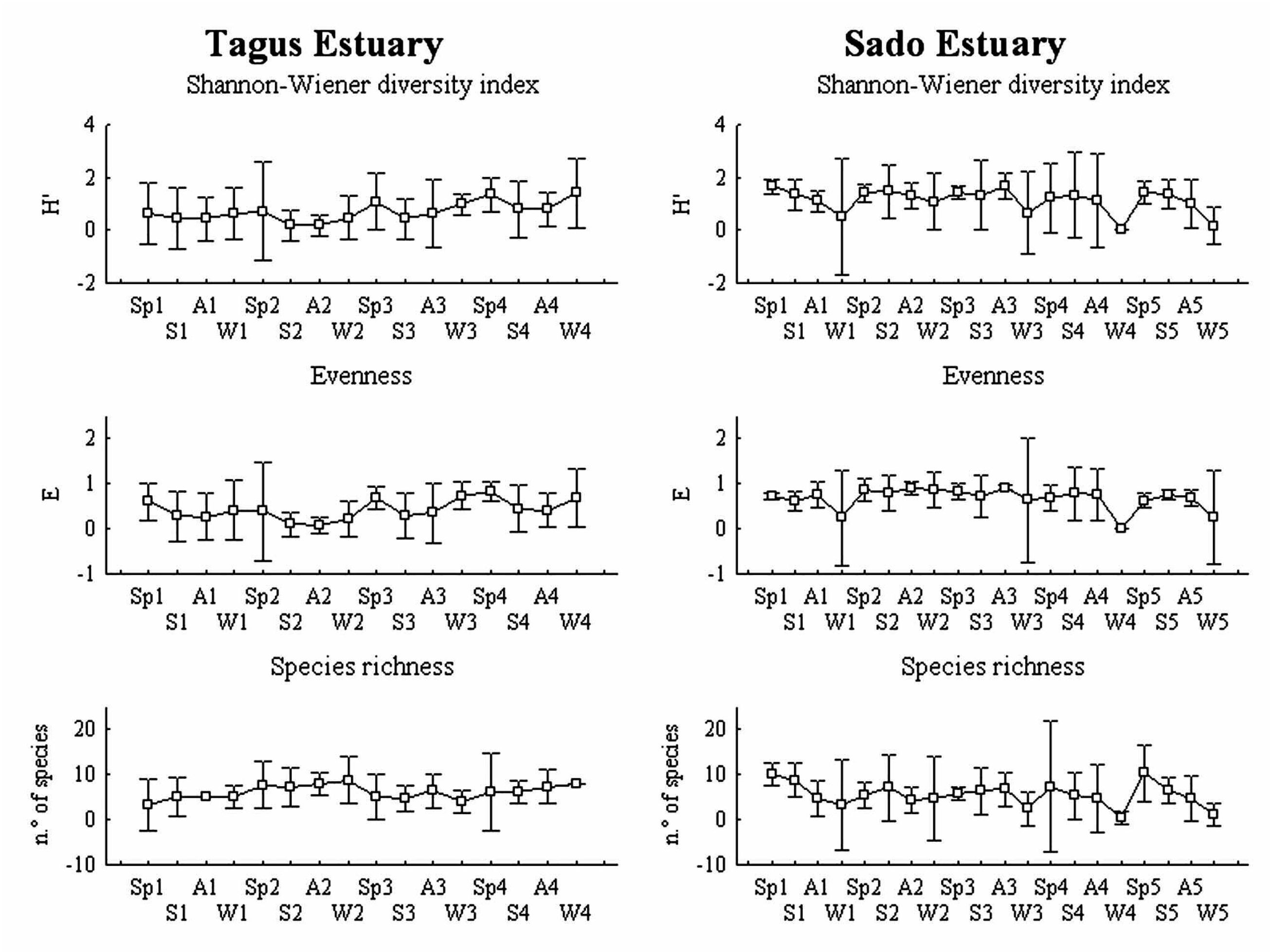


Figure 6. Species diversity, evenness and species richness indices variation for sample sites in the two estuaries along the year.

Figure 6. Variation des indices de diversité, régularité et richesse spécifique aux stations échantillonnées dans les deux estuaires pendant l'année.

1758) (DPS), short snouted seahorse *Hippocampus hippocampus* (Linnaeus, 1758) (HPH), salema *Sarpa salpa* (Linnaeus, 1758) (SRS), Thor's scaldfish *Arnoglossus thori* Kyle, 1913 (ART), and whiskered sole *Monochirus hispidus* Rafinesque 1814 (MNH) is mainly associated with the sample 2 and 3 of the Sado estuary. This group is closely related to high salinity (Sal) and with sediment of higher grain size particles.

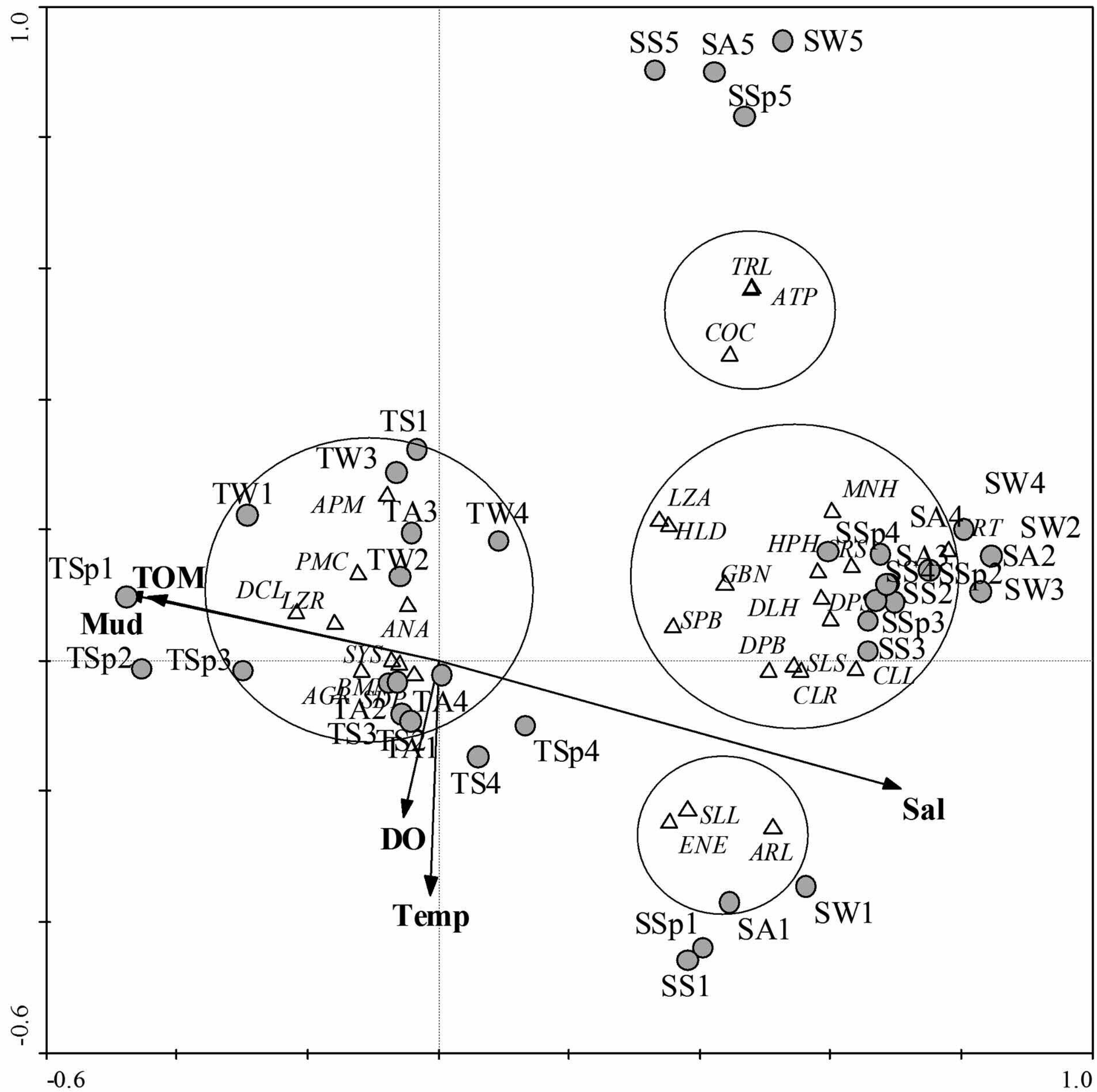
A second group represented by the species European seabass *Dicentrarchus labrax* (Linnaeus, 1758) (DCL), thinlip grey mullet *Liza ramada* (Risso, 1810) (LZR), pipefish *Syngnathus* sp (SYS), meagre *Argyrosomus regius* (Asso, 1801) (AGR), *P. minutus* (PMN), common goby *Pomatoschistus microps* (Krøyer, 1838) (PMC), sardine *Sardina pilchardus* (Walbaum, 1792) (SDP), transparent goby *Aphia minuta* (Risso, 1810) (APM) and European eel *Anguilla anguilla* (Linnaeus, 1758) (ANA), is mostly associated with the Tagus estuary, being mainly influenced by low salinity and sediment with both a high level of fine particles (Mud) and high organic matter (TOM).

The third and fourth groups of species are influenced by an environment with high salinity and high percentage of mud and were present in the Sado estuary. The third group is more correlated with the sampling area 5, characterized by the presence of the sand smelt, *Atherina presbyter* Cuvier, 1829 (ATP), the gurnard, *Trigla lucerna* (Linnaeus, 1758) (TRL) and the European conger *Conger conger* (Linnaeus, 1758) (COC). The fourth group encloses the anchovy, *Engraulis encrasicholus* (Linnaeus, 1758) (ENE), *S. solea* (SLL) and *A. laterna* (ARL) and is strictly associated with sampling area 1.

The environment parameters dissolved oxygen (DO) and temperature (Temp), negatively correlated with the second axis, have a weaker influence in the ordination when compared with the other variables.

Table 4. Values of the Kruskal-Wallis test for the diversity indices. Significant values ($\alpha < 0.05$) are signed with *.
Tableau 4. Résultats du test de Kruskal-Wallis sur les indices de diversité. Les valeurs significatives ($\alpha < 0.05$) sont signalées par *.

	Among Seasons				Among Sites			
	Tagus		Sado		Tagus		Sado	
	Kruskal-Wallis test H	p value	Kruskal-Wallis test H	p value	Kruskal-Wallis test H	p value	Kruskal-Wallis test H	p value
Shannon index	8.4910	0.0369*	19.7890	< 0.001*	13.9970	0.0029*	2.8133	0.5895
Evenness	14.2630	0.0026*	5.4000	0.1446	13.2980	0.0040*	16.9900	0.0019*
Species richness	2.7180	0.4371	23.5100	< 0.001*	19.2620	< 0.001*	3.9390	0.4144



Discussion

Both the Tagus and Sado estuary are greatly influenced by anthropogenic activities. Important industrial complexes such as chemical, petrochemical, food processing and smelting are present in both estuaries, mainly in their lower part while, in the upper parts, they are bordered by land used intensively for agriculture and aquaculture (in the case of the Sado estuary). All these activities generally contributed to an impoverishment of water quality until the end of the 1980s. The creation of both the Tagus and Sado Natural reserves (in 1976 and 1980, respectively) was associated with the construction of water treatment plants and the elimination of effluents which have largely contributed to an improvement of water quality.

Present conditions in both estuaries are clearly favourable to the presence of a diverse fish assemblage. It must be pointed out that, although the area occupied by the Sado estuary is almost half of the Tagus estuary, the former contains a fish assemblage characterized by a higher species richness which is, in fact, one of the highest found among Portuguese estuaries (Cunha, 1994). Besides high productivity, high richness is probably due to the diversity of habitats (oyster beds, mud flats, ellgrass beds) and a predominant marine influence of the Sado estuary. In fact, as Whitfield (1994) pointed out, estuaries that constitute coastal bays (as Sado estuary) present a higher diversity when compared to other estuarine environments.

The richer fish assemblage present in the Sado estuary was also shown by the diversity indices which expressed the structure of assemblages in terms of species composition and abundance. They have been used in a number of studies of assemblages of estuarine fish populations (e.g. Costa & Bruxelas, 1989), both as a measure of the fluctuation in estuarine populations due to immigration and emigration and as a measure of the effects of stress, particularly pollution stress, at the assemblage level.

Comparing the fish assemblage of Tagus estuary with the one that was studied during 1980s (Costa, 1982; Costa & Bruxelas, 1989), a decrease in its diversity can be noticed. In fact, Costa (1982) found 3 elasmobranch and 39 teleost species in her pioneer study on the structure of the fish assemblage of the Tagus estuary. Among the species that are no longer present or are seldom caught are some diadromous species (the allis shad, *Alosa alosa* (Linnaeus, 1758), the twaite shad, *Alosa fallax* (Lacépède, 1803), the flounder, *Platichthys flesus* (Linnaeus, 1758)) and some typical freshwater species (the carp, *Cyprinus carpio* Linnaeus, 1758, and the barb, *Barbus bocagei* Steindachner, 1864). According to Assis et al. (1992), the main causes for the impoverishment of the estuarine community and the staid decline of diadromous species were the increase of pollution levels (more than 600 industrial pollution sources were inventoried), over fishing, dams (due not only to their physical obstruction but also to the modifications that they produce on estuary hydro-dynamics) and the loss of habitat (and the areas initially chosen by fish for reproduction).

Despite their geographical proximity, the Tagus and Sado estuaries present fish communities with contracting ecological guilds structure. Marine juvenile species dominated the Sado estuary fish community in terms of species density, a situation that has been found in a wide variety of estuarine systems in Europe and worldwide (Haedrich, 1983; Elliott & Dewailly, 1995). However, in the Tagus estuary, the highest densities were reported for resident species, a fact that has been reported to this estuary since the 1980s (Costa, 1982; Cabral, 1998) and commonly observed in other estuaries along the Portuguese coast (Monteiro, 1989; Rebelo, 1992; Cabral et al., 2001; Gordo & Cabral, 2001). This situation is different from the one that occurs in northern European estuaries (e.g. the Severn and Elbe estuaries) where the marine and/or diadromous species are present in larger numbers than the resident species.

The contribution of the marine juvenile group is high in both the Sado and Tagus estuaries showing that they provide nursery grounds for a large variety of species and this is true of other Portuguese estuaries (Costa et al., 2002; Monteiro, 1989; Rebelo, 1992). However, in a period of 3 decades, the pounting, *Trisopterus luscus* (Linnaeus, 1758), *P. flesus*, *T. lucerna* and the fivebeard rockling, *Ciliata mustela* (Linnaeus, 1758), that were very abundant at that

Figure 7. Canonical Correspondence Analysis ordination diagram relative to data on fish densities. The first two ordination axes are represented. Open triangles refer to species (codes in the results section); full circles refer to estuary-season-site (estuary: S, Sado; T, Tagus. Seasons: Sp, spring; S, summer; A, autumn; W, winter. Sites: 1 to 5); arrows refer to environmental variables (Temp, temperature; DO, dissolved oxygen; Mud, mud; Sal, salinity; TOM, total organic matter).

Figure 7. Diagramme de l'analyse canonique des correspondances selon la densité du poisson. Les deux premiers axes sont représentés. Les triangles ouverts désignent les espèces (voir codage à la section des résultats) ; les cercles désignent les estuaires-saisons-points (estuaire : S, Sado ; T, Tage. Saisons : Sp, printemps ; S, été ; A, automne ; W, hiver. Points : 1 à 5) ; les flèches représentent les variables environnementales (Temp, température ; DO, oxygène dissous ; Mud, vase ; Sal, salinité ; TOM, matière organique totale).

time (Costa, 1984; Costa & Bruxelas, 1989) no longer use the Tagus estuary as a nursery area (Cabral, 1998).

The absence of typical freshwater species in both estuaries is probably related to the relatively high salinity present (particularly in the Sado estuary), preventing their presence in the estuaries even in its upper part.

Canonical correspondence analysis (CCA) has been widely used to describe the major patterns of fish assemblages (Godinho & Ferreira, 1998; Castillo-Rivera et al., 2002) and to evaluate the relationships with environmental factors (e.g. Elliott & Marshall, 2000). There were marked differences in the spatial and seasonal pattern between the Sado and Tagus fish assemblages. The Tagus estuary assemblage was dominated by the resident species and the marine juveniles, particularly those that enter the estuary for food and protection (e.g. *D. labrax*) or even hatched there (e.g. *A. regius*). These two groups of species have in common the high tolerance to euryhaline environments and it is probable that lower salinity in Tagus estuary is therefore favourable to their presence. The Sado estuary assemblage was mainly composed of marine juveniles and occasional marine species that are usually present in the lower zones of estuaries. The elevated salinity in the Sado estuary during all the year, favours the dominance of marine species in the fish assemblage. Although salinity is the principal abiotic factor that seemed to discriminate these two fish assemblages, the influence of other environmental factors (or combination of factors) likely play additional roles. Also biotic factors such as density-dependency considered of great importance in niche segregation of estuarine fish species (Darnaude et al., 2001) may also play a role in the fish distribution in the Sado estuary. Furthermore, the variety of seasonal migrants from all life history classifications suggests the multiple roles of Sado estuary in providing shelter and foraging sites for juvenile fish as well as a spawning habitat and an appropriate physicochemical environment for adult fishes (Ayvazian et al., 1992).

In conclusion, the Tagus and Sado estuaries are located in the proximity of large cities and potentially under harmful influence as a result of anthropogenic activities (including dredging). Nevertheless, both estuaries have been able to maintain very important ichthyological systems that support resident species, provide a suitable nursery area to marine migratory species and protection for many occasional species, particularly in their juvenile stages.

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