

# The structure and functioning of fish communities in the Ria de Aveiro, Portugal – temporal and spatial variations and the influence of abiotic factors

Lúcia POMBO<sup>1</sup>, Mike ELLIOTT<sup>2</sup> and José Eduardo REBELO<sup>1</sup>

(<sup>1</sup>) *University of Aveiro, Department of Biology, 3810-193 Aveiro – Portugal*

(<sup>2</sup>) *University of Hull, Institute of Estuarine & Coastal Studies, Hull, HU6 7RX – UK*

*Fax: +35123426408; Email: LPombo@bio.ua.pt*

**Abstract:** The ichthyofauna and environmental variables were sampled monthly over a 2-year period, from November 1998 to October 2000, at 9 sites in the Ria de Aveiro, northern Portugal. Temperature, salinity, dissolved oxygen, pH and turbidity showed significant temporal variations, while salinity, pH, turbidity and depth showed significant spatial variations. A total of 41,681 individuals from 61 species were collected, with a total biomass of 222 Kg wet weight. Species richness was statistically higher in 1999 than in 2000, with peaks in spring-summer in both years, which could be attributed to an influx of marine seasonal migrant species and marine juvenile species. Diversity and evenness were significantly higher in 1999 than 2000 with peaks in spring and autumn and low values in June for the first year, and in February and November for the second year and corresponding to the large recruitment of adult marine seasonal and adventitious species. Spatially, both indices were higher at the intermediate regions of the lagoon. Salinity was found to be the best predictor of total biomass, with temperature also having a major role. Temperature, salinity and pH were positively correlated with species richness and depth was negatively correlated with species richness. It is concluded that the abiotic factors were related to the distribution and diversity of the ichthyofauna such that seasonal changes in abiotic factors appeared to be of greater importance in explaining variations in the fish communities than location within the lagoon.

**Résumé:** *Structure et fonctionnement de la communauté ichthyique du Ria de Aveiro, Portugal - variations spatiales et temporelles et influence des facteurs abiotiques.* L'ichtyofaune et les variables environnementales ont été échantillonnées mensuellement pendant deux ans, de novembre 1998 à octobre 2000, en 9 sites du Ria de Aveiro, au nord du Portugal. La température, la salinité, l'oxygène dissous, le pH et la turbidité montrent des variations temporelles significatives ; la salinité, le pH, la turbidité et la profondeur montrent des variations spatiales significatives. Un total de 41 681 individus répartis en 61 espèces a été récolté, pour une biomasse de 222 kg de poids frais. La richesse spécifique est significativement supérieure en 1999 qu'en 2000 ; elle est caractérisée par des maxima au printemps-été au cours des deux années, qui pourraient être attribués à l'afflux d'espèces marines saisonnières ou juvéniles. La diversité et la régularité sont significativement plus fortes en 1999 qu'à celles de 2000 avec des maxima au printemps et en automne ; de faibles valeurs en juin la première année et en février et novembre la seconde année correspondent à un important recrutement d'espèces marines. Spatialement, les deux indices sont plus élevés dans les parties intermédiaires de la lagune. La salinité, ainsi que la température sont les facteurs les mieux corrélés à la biomasse totale. La température, la salinité et le pH sont corrélés positivement à la richesse spécifique alors que la profondeur y est corrélée négativement. Les relations mises en évidence entre les facteurs abiotiques et la distribution ainsi que la diversité de l'ichtyofaune montrent l'importance des variations saisonnières des facteurs environnementaux sur celles de la structure de l'ichtyofaune, davantage que sur la localisation au sein de la lagune.

**Keywords:** Fish diversity, Estuarine lagoon, Abiotic variables, Ria de Aveiro

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## Introduction

Assemblages of estuarine organisms change continually in time and space, largely because estuaries serve as nurseries for many marine and estuarine dependent species (Rogers et al., 1984 in Rakocinski et al., 1996; Elliott & Hemingway, 2002). The habitats and, therefore, potentially the fish assemblages, can be affected by anthropogenic influences that vary with time and space. These impacts can have a direct influence on the food resources, distribution, abundance, growth, survival and behaviour of fish in aquatic environments (Whitfield, 1996). The linkages between the changes in the ichthyofauna and environmental variation in estuaries suggest that fish species or fish communities are sensitive indicators of the relative health of an aquatic ecosystem (Karr, 1981). The importance of estuaries for fish has resulted in environmental quality objectives (EQO) being adopted to manage estuaries, to protect estuarine habitats and to ensure that water quality is suitable for sustaining healthy fish populations (Elliott et al., 1988). These fish-orientated EQO include: (i) the water quality always allows the passage of migratory fish; (ii) the estuary's residential fish community is consistent with the hydro physical conditions; (iii) the benthos and sediments are of sufficient quality to support the fish populations, and (iv) the levels of persistent toxic and tainting substances in the biota should be insignificant and should not affect predatory fish (Elliott et al., 1988). According to Whitfield (1996), biological monitoring is preferred to chemical monitoring because the latter can fail to detect many of the anthropogenic-induced perturbations of aquatic systems and biological monitoring will integrate all changes occurring in the environment.

In order to determine whether the perceived degradation of a system is actual and to what degree it has occurred, it is necessary to distinguish between natural and anthropogenic changes to the biological assemblages in that system over space and time (Matthews, 1998). However, multispecies assemblages vary greatly and are rarely quantified over both space and time (James, 2001). Despite this, recent developments in estuarine and coastal management within Europe, such as the European Union Water Framework (WFD) and Habitats Directives, require further study on the status of priority habitats such as estuaries and lagoons. It is of note that the WFD requires reference conditions to be derived for the fish communities of transitional waters, which includes estuaries and lagoons, against which anthropogenic change can be judged.

The Ria de Aveiro is an estuarine lagoon ecosystem, with one narrow entrance to the sea; it is an ecotone with fluvial and marine influences, shallow depth, high turbidity, high nutrients, muddy substratum and seasonal fluctuations of temperature, salinity, dissolved oxygen, pH and

turbidity. The system also has considerable fish diversity (Rebelo, 1992; Pombo & Rebelo, 2002; Pombo et al., 2002) but also provides an important area for the exploitation of commercial and sport fisheries. The ecological studies of ichthyofauna in this system assume considerable economic relevance due to the exploitation of fish within the lagoon.

The lagoon represents an area of considerable economic importance for the region: i) in the primary sector - agriculture, fisheries, aquaculture, and salt-production; ii) in the secondary sector, as a dominant area for industry in the region of Aveiro; iii) in the tertiary sector - tourism, particularly water-borne sports, sport fisheries, passenger transport and services associated with these practices. These activities affect the quality of the water and the sediments of the lagoon by the introduction of chemical, organic and microbial pollutants (Lucas et al., 1986; Borrego et al., 1994). Thus, the lagoon receives considerable raw and treated wastewater effluent such that three main pollution types are apparent: organic and chemical pollution from paper-pulp factories (in the rivers of Vouga and Antuã); chemical pollution, particularly mercury, from the industrial area of Estarreja (in Laranjo area); and microbial contaminants from the urban sewage effluent and cattle raising areas (Ílhavo channel, Vouga river and Ovar channel) (Hall, 1980; Lima, 1986; Lucas et al., 1986; Borrego et al., 1994).

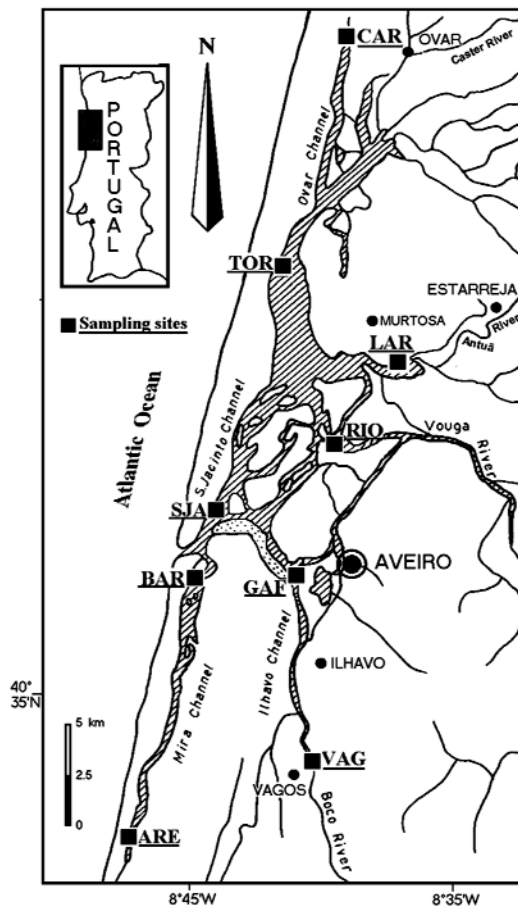
Previous studies of ichthyofauna in this lagoon (Osório, 1912; Nobre et al., 1915; Arruda et al., 1988; Rebelo, 1992; Pombo & Rebelo, 2000, 2002) provide information on the behaviour and evolution of the lagoon fish assemblage (Pombo et al., 2002) and their relation with the adjacent oceanic communities.

The present study was designed to characterize the fish assemblages occurring in a typical estuarine lagoon in the littoral of Portugal and to detect significant temporal and spatial differences in those assemblages. It aimed to identify correlations between species assemblages with different ecological guilds and abiotic conditions and to identify factors responsible for maintaining the structure of fish assemblages. The results of this work provide baseline information for monitoring the status of and change within these systems and for comparisons with similar lagoonal systems.

## Material and methods

### *Study Area*

The Ria de Aveiro (Fig.1), on the west coast of Portugal, is an estuarine lagoon, 45 km long with a maximum width of 11 km. Its total area is between 42 km<sup>2</sup> at low tide, and 47 km<sup>2</sup> at high tide (Barrosa, 1980). The depth at low tide is only 1 m over much of the lagoon, but can reach 10 m near the mouth and in the navigation channels. Riverine fresh-



**Figure 1.** Map of the Ria de Aveiro lagoon showing sampling sites.

**Figure 1.** Carte de la Ria du lagon de Aveiro, montrant les sites d'échantillonnage.

water is mixed with seawater entering from the mouth and the tidal input is approximately between 25 and 90.10<sup>6</sup> m<sup>3</sup> for tidal amplitudes of 1 and 3 m respectively. The water volume is 70 millions m<sup>3</sup>, with an oceanic tidal contribution between 25 millions m<sup>3</sup> (neaptides) and 90 millions m<sup>3</sup> (spring tides). Four rivers (Vouga, Antuã, Caster and Boco) and innumerable streams flow into it at a rate between 3 m<sup>3</sup>s<sup>-1</sup> and 60 m<sup>3</sup>s<sup>-1</sup>, depending on the seasonal precipitation and runoff patterns. Communication with the sea is through a 400 m wide entrance in the coastal sand-bar structure (Barrosa, 1980) and the currents produced by this tidal action are significant only at the mouth, the central part of the main channels and a few other restricted areas. There is a delay of 6 hours in the times of high and low water between the mouth and the extreme margins of the lagoon. The sediment composition, in particular the granulometry, is extremely variable and varies between 20 to

90% sand, 10 to 80% silt and 0 to 30% clay. The inner lagoonal areas have accreting conditions as shown by the northern finer sediments which become progressively coarser to the south (Borrego et al., 1994).

#### Sampling Method

The ichthyofauna was sampled monthly from November 1998 to October 2000 at nine sampling sites (Fig.1). The first twelve months of sampling are designated as 1999 and the second as 2000. At each site and each month, 3 non-overlapping replicate samples were taken at low spring tide, over the five days of the new moon. The total area enclosed by the gear was approximately 193 m<sup>2</sup> in each trawl. A "chinchá" or traditional beach-seine net (Nobre et al., 1915) was used to sample fish. The "chinchá" gear used was almost rectangular in shape and composed by a central bag (a 'cod-end', 295 cm of length and 145 cm of wide), two lateral wings (12 m of length each, the width decreasing along the net, reaching 50 cm at the edge), two ropes (6.1 m each), floating buoys at the top and ceramic weights at the bottom of the net. The stretched mesh sizes in the gear were 19 mm at the wings, 17 mm at the cod mouth, 16 mm at the cod sleeve, and 10 mm at the cod-end. The end of the net was fixed to the margin and the remainder was trawled in a semi-circle thus retaining within the cod-end all the fish from the area. The net efficiency is estimated at 90% (Elliott & Hemingway, 2002).

The abiotic parameters temperature, salinity, dissolved oxygen, pH, turbidity and depth were recorded at each site and each month, according to previous studies (Rebello, 1992; Pombo & Rebello, 2000, 2002). Temperature ( $\pm 0.1^{\circ}\text{C}$ ) and dissolved oxygen ( $\pm 0.01 \text{ mg.l}^{-1}$ ) were recorded with an oxygen meter (*Consort Z621*), the salinity ( $\pm 0.1$ ) with a refractometer (*Atago*), the pH ( $\pm 0.01$ ) with a pHmeter (*WTW 330/set - 2*), the turbidity ( $\pm 0.1 \text{ m}$ ) with a Secchi disc and the depth ( $\pm 0.1 \text{ m}$ ) with a handmade probe. The abiotic parameters were spatially and temporally compared between the two years of sampling.

After capture, fishes were preserved by freezing, and were individually identified in the laboratory according to Whitehead et al. (1986) and Bauchot & Pras (1987). The total fresh weight was measured with an electronic balance (*And FX - 300*).

#### Data Analysis

Species were grouped into ecological guilds using the method of Elliott & Dewailly (1995) according to their biology and behaviour and using background information for the lagoon (Osório, 1912; Nobre et al., 1915; Arruda et al., 1988; Rebello, 1992; Pombo & Rebello, 2000, 2002). The categories were: estuarine resident species, marine juvenile migrant species, marine seasonal migrant species, freshwater

adventitious species, marine adventitious visitors and diadromous (catadromous or anadromous) migrant species.

Factors including month, site, year, and interaction terms between them (month\*site, month\*year, site\*year, and month\*site\*year) were tested for the abiotic parameters and for the diversity indices (species richness, species diversity and evenness indices) using two-way ANOVA and three-way ANOVA (Zar, 1984; Sokal & Rohlf, 1995). Homogeneity of variances was tested using the Fmax test (Zar, 1984; Sokal and Rohlf, 1995). Square root transformations of temperature and salinity and  $\log_{10}$  transformations of Shannon-Wiener and evenness were performed to comply with assumptions of the analysis (Zar, 1984; Sokal and Rohlf, 1995). The package Sigma-stat for windows version 2.03 was used for these analyses.

Species richness, species diversity and evenness indices were used to characterise the temporal and spatial biomass of the ichthyofauna (Ludwig & Reynolds, 1988). The species richness (R) was quantified by the Margalef index (Ludwig & Reynolds, 1988):

$$R = \frac{S-1}{\ln(n)}$$

where  $S$  indicates the total number of species and  $n$ , the total number of individuals in a sample. Species diversity was quantified using the Shannon-Wiener index ( $H'$ ) (Shannon & Weaver, 1949):

$$H' = -\sum_{i=1}^S \left[ \left( \frac{n_i}{n} \right) \log_2 \left( \frac{n_i}{n} \right) \right], i = 1, 2, 3, \dots, S$$

where  $S$  indicates the total number of species,  $n_i$  the abundance of the  $i$  species, and  $n$  the abundance of all species. Evenness (E) was quantified by the index modified by Hill (1973):

$$E = \frac{\frac{1}{\lambda} - 1}{e^{H'} - 1} = \frac{N_2 - 1}{N_1 - 1}$$

where  $\lambda$  represents the Simpson index,  $H'$  the Shannon-Wiener index and  $N_2$  and  $N_1$  represents the diversity number.

Pearson parametric (product-moment) correlation coefficients were used to determine the statistical significance of any relationship between species richness and diversity indices and each abiotic factor to identify which parameter contributes to explaining the structure of fish assemblages in each year (Sokal & Rohlf, 1995). Similarly, Pearson correlations were used to determine the statistical significance of any relationships between fish biomass and abiotic factors to be analysed individually (Sokal & Rohlf, 1995), thus determining the independent variables most likely to

explain the distribution of each species together with the nature of the effect.

Seasonal and spatial patterns in habitat structure and fish communities were examined by use of multivariate cluster and ordination techniques. A cluster (classification) analysis was performed using the Bray-Curtis similarity coefficient and UPGMA (unweighted, pair-group, methods using arithmetic averages) linkage method (Boesch, 1977) and a multi-dimensional scaling (MDS) ordination was carried out on log-transformed  $\log_{10}(x+0.1)$  species biomass data (ter Braak, 1988). This strong transformation was chosen so that the few species with high biomass would not be over-emphasized in the determination of clusters. The package MVSP (Multi-Variate Statistical Package) (Kovack, 1998) was used for these analyses.

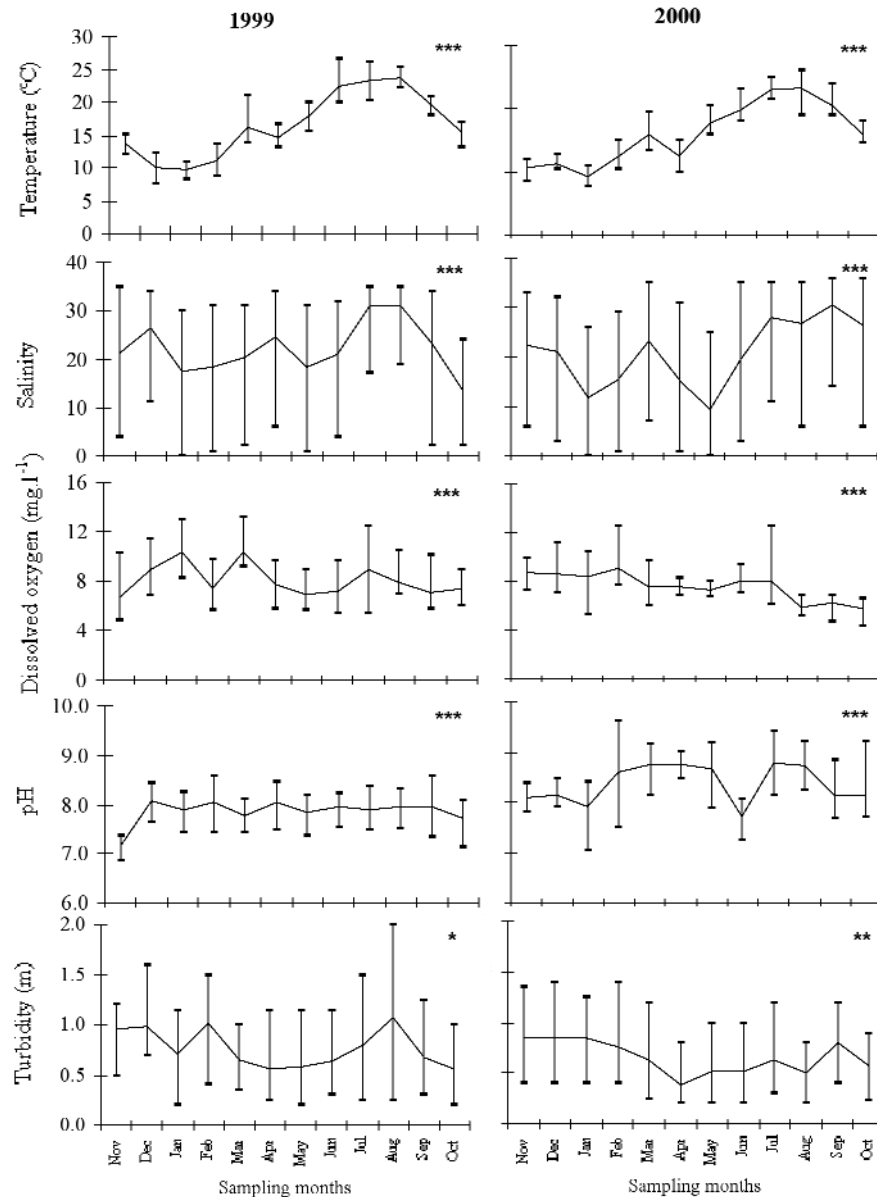
A further ordination technique, canonical correspondence analysis (CCA) was used as a dual ordination of the species (R-mode) and sites (Q-mode) data together with the environmental parameters (Ter Braak, 1988). To avoid problems associated with the "arch effect" of correspondence analysis, only the ten most abundant species (Table 2) were included in the analysis (Jongman et al., 1995). CCA gave an assessment of the relative importance of the parameters to the distribution of each of these ten species (Ter Braak, 1988).

## Results

### Abiotic Parameters

The average, minimum and maximum values of the environmental data in each month and site for each year are shown in figures 2 and 3. Each sampling site is presented in the graphs according to the minimum distance from the lagoon entrance. Each factor analysed, except depth, showed temporal variation (Fig. 2), and salinity, pH, turbidity and depth showed significant spatial variation (Fig. 3). Interactions between months and sites, and between months, sites and years showed no significant differences in any abiotic parameter although much of the abiotic variation appeared to be related to seasonal (climatic) cycles. Interactions between months and years showed significant differences in pH ( $p < 0.001$ ) being higher in the second year at all sites, especially in spring. Interactions between sites and years showed a significant depth decrease ( $p < 0.001$ ) in the second year at most of sites (with the exception of the shallow sites - ARE, BAR and TOR).

Temperature varied from 27°C in summer to 7.6°C in winter (Fig. 2) and dissolved oxygen varied from hypoxic levels (4 mg.l<sup>-1</sup>) in winter to oversaturated values (13 mg.l<sup>-1</sup>) in summer. Salinity varied with distance from the mouth of the lagoon from typically freshwater (ARE

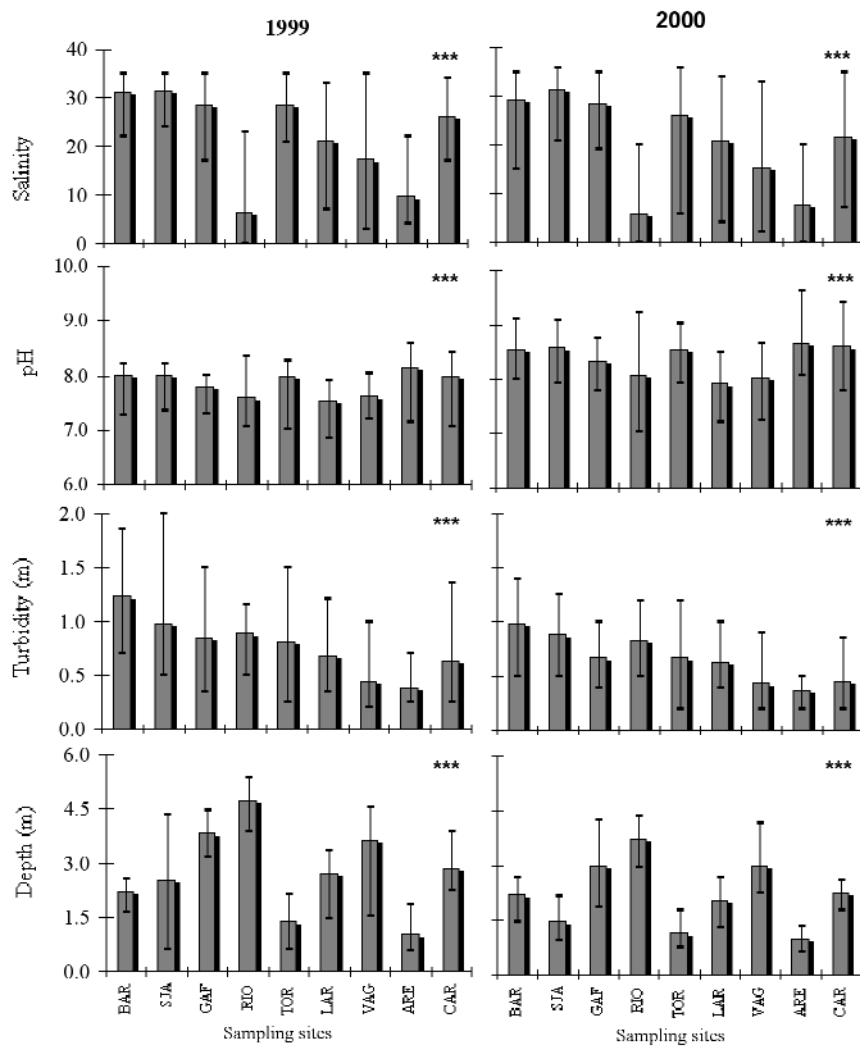


**Figure 2.** Minimum, average and maximum values of abiotic parameters by sampling months, in each year. Only abiotic parameters with significantly differences between months are shown: (\*):  $p < 0.05$ , (\*\*):  $0.001 < p < 0.01$ ; (\*\*\*):  $p < 0.001$ .

**Figure 2.** Valeurs minimales, moyennes et maximales des paramètres abiotiques par mois d'échantillonnage, pour chaque année. Seuls les paramètres abiotiques avec des différences significatives entre les mois sont montrés : (\*) :  $p < 0,05$  ; (\*\*) :  $0,001 < p < 0,01$  ; (\*\*\*)  $p < 0,001$ .

and RIO), brackish water (VAG, LAR and CAR), and marine water (BAR, SJA, GAF and TOR) (Fig. 3). In areas less subject to the buffering activity of seawater, the pH varied between acid (6.81) in the regions with higher chemical pollution problems (LAR) (Fig. 1) (Pombo et al.,

2000) and alkaline (9.62) in the regions with urban effluents and farming activities (Ílhavo channel, Vouga River and Ovar channel) (VAG, RIO and CAR) (Fig.1). The turbidity, as shown by the light penetration depth, varied from 20 cm, at the edges during summer, to 2 m, near the mouth



**Figure 3.** Minimum, average and maximum values of abiotic parameters by sampling sites, in each year. Only abiotic parameters with significant differences between sites are shown: (\*\*\*) :  $p < 0.001$ .

**Figure 3.** Valeurs minimales, moyennes et maximales des paramètres abiotiques par site d'échantillonnage, pour chaque année. Seuls les paramètres abiotiques avec des différences significatives entre les sites ont été montrés : (\*\*\*) :  $p < 0.001$ .

of the lagoon during winter (Figs. 2 and 3). Finally, the depth increased from the edges of channels (0.5 m) (ARE at south and TOR at north) to the deepest sites in the inner regions of the lagoon (6 m) (RIO, VAG and LAR) (Fig. 3).

#### *Structure of the fish community*

In this study 41,681 specimens comprised of 61 teleost species were captured, with a total biomass of 222 Kg (Table 1). Of the 61 species captured over the two years of sampling, only 33 species were common to both years, 20

species were exclusive to 1999 and 8 were exclusive to 2000 (Table 1). The decrease in number of species, from 1999 to 2000, was due to the absence in the second year of 10 marine adventitious visitors, 8 marine juvenile migrant species and 2 estuarine resident species (Table 2); however these were replaced by others in 2000: 3 marine adventitious, 2 freshwater, 1 estuarine resident, 1 marine juvenile, and 1 anadromous species. The number of total individuals was slightly higher in 2000 (Table 1), although the biomass was similar in both years.

The marine seasonal accounted for 57% of total biomass

**Table 1.** Number of individuals, biomass and total number of species in the two years of sampling.**Tableau 1.** Nombre d'individus, biomasse et nombre total d'espèces au cours des deux années d'échantillonnage.

Total	1999	2000	Total
Number of individuals	19,424	22,257	41,681
Biomass (kg)	112.6	109.3	221.9
<b>Samples species number</b>			
Number of species	53	41	61
Exclusive species per year	20	8	
Common species in two years			33

collected during the whole period (Table 2). Thirteen species were marine juvenile migrant species, comprising 8% of total numbers and 13% of total biomass. Twenty species were transient visitors to the lagoon, but they com-

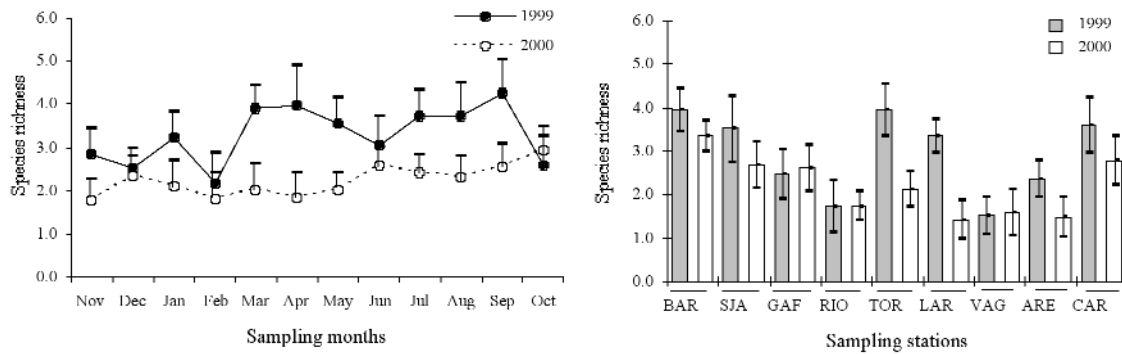
prised a low number of the fish collected (1% of total individuals and 3% of total biomass). Only five species were anadromous and one catadromous accounting for 6% of total individuals and 13% of the total biomass. Only two freshwater species were collected and of these 7 individuals occurred sporadically in the lagoon (Table 2).

*Sardina pilchardus* was the most abundant species in both years, comprising 44% of total numbers and 12% of total biomass, followed by *Liza aurata* (Table 2), which was the species with the highest biomass (more than 40% in each year) (Table 2).

From the ten selected dominant species (represented in bold type in Table 2), six were present at every sampling site and three were evenly distributed in all seasons: *Atherina boyeri*, *A. presbyter* and *L. aurata*. *Dicentrarchus labrax* occurred in larger numbers in summer and autumn, while *S. pilchardus*, *Liza ramada* and *Liza saliens* were more seasonal, being entirely absent or rare during winter and occurring in greatest numbers in spring, summer, and sometimes autumn.

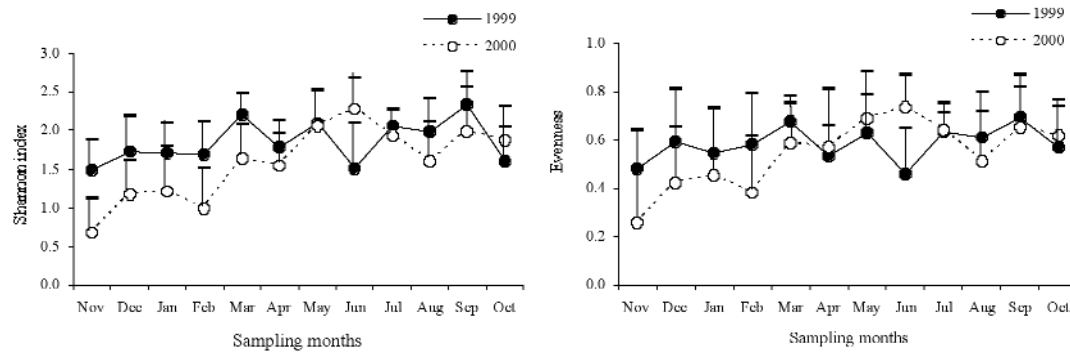
**Table 2.** Number of individuals and biomass (g) of fish sampled in 1999 and 2000 grouped by ecological guilds, according to Elliott & Dewailly (1995). Dominant species for CCA analysis are in bold.**Tableau 2.** Nombre d'individus et biomasse (g) de poissons échantillonnés en 1999 et 2000 regroupés en associations écologiques selon la méthode d'Elliott & Dewailly (1995). Les espèces dominantes pour l'analyse CCA sont en gras.

Species	Code name	Abundance		Biomass (g)		Species	Code name	Abundance		Biomass (g)	
		1999	2000	1999	2000			1999	2000	1999	2000
Estuarine Resident Species						Freshwater Adventitious Species					
<i>Ammodytes tobianus</i>	Atob	9	0	102.1	0.0	<i>Carassius carassius</i>	Ccar	0	3	0.0	1,346.4
<i>Aphia minuta</i>	Amin	48	5	9.3	4.5	<i>Gambusia affinis</i>	Gaff	0	4	0.0	1.9
<b><i>Atherina boyeri</i></b>	<b>Aboy</b>	<b>2,082</b>	<b>2,911</b>	<b>5,624.7</b>	<b>3,074.2</b>	Marine Adventitious Visitors					
<i>Gobius ater</i>	Gate	1	4	9.4	54.0	<i>Balistes carolinensis</i>	Bcar	1	0	379.4	0.0
<i>Gobius niger</i>	Gnig	182	235	2,732.5	3,026.8	<i>Boops boops</i>	Bboo	2	1	89.8	0.4
<i>Gobius paganellus</i>	Gpag	18	2	189.4	13.4	<i>Callionymus lyra</i>	Cllyr	12	6	211.1	116.9
<i>Mugil cephalus</i>	Mcep	8	5	2,457.0	2,056.7	<i>Conger conger</i>	Ccon	1	0	0.6	0.0
<i>Nerophis ophidion</i>	Noph	1	0	3.0	0.0	<i>Deltentosteus quadrimaculatus</i>	Dqua	1	0	9.0	0.0
<i>Platichthys flesus</i>	Pfle	121	21	988.5	250.7	<i>Echiichthys vipera</i>	Evip	0	1	0.0	19.2
<b><i>Pomatoschistus microps</i></b>	<b>Pmic</b>	<b>526</b>	<b>338</b>	<b>443.4</b>	<b>192.3</b>	<i>Entelurus aequoreus</i>	Eaeq	0	1	0.0	0.8
<i>Pomatoschistus minutus</i>	Pmin	75	47	69.3	105.1	<i>Hyperoplus lanceolatus</i>	Hlan	1	0	2.6	0.0
<i>Symphodus melops</i>	Smel	0	1	0.0	14.8	<i>Labrus bergylta</i>	Lber	2	0	140.1	0.0
<i>Syngnathus acus</i>	Sacu	203	200	729.3	1,063.8	<i>Labrus merula</i>	Lmer	1	0	59.4	0.0
<i>Syngnathus typhle</i>	Styp	6	6	15.2	2.6	<i>Mullus surmuletus</i>	Msur	21	12	893.3	598.9
Marine Juvenile Migrant Species						<i>Parablennius gattorugine</i>	Pgat	8	10	37.8	45.0
<b><i>Atherina presbyter</i></b>	<b>Apres</b>	<b>1,011</b>	<b>1,225</b>	<b>7,078.3</b>	<b>6,896.0</b>	<i>Parablennius sanguinolentus</i>	Psan	1	0	7.6	0.0
<i>Chelidonichthys lucerna</i>	Cluc	202	32	4,569.9	977.0	<i>Pomatoschistus marmoratus</i>	Pmar	7	0	22.5	0.0
<b><i>Dicentrarchus labrax</i></b>	<b>Dlab</b>	<b>37</b>	<b>757</b>	<b>1,456.0</b>	<b>7,954.5</b>	<i>Psetta maxima</i>	Pmax	1	0	49.4	0.0
<i>Dicentrarchus punctatus</i>	Dpun	5	0	34.4	0.0	<i>Scomber scombrus</i>	Ssco	1	0	19.2	0.0
<i>Diplodus annularis</i>	Dann	2	0	14.9	0.0	<i>Solea lascaris</i>	Slas	11	2	55.3	24.1
<i>Diplodus sargus</i>	Dsar	20	5	94.3	30.3	<i>Sparus aurata</i>	Saur	0	8	0.0	97.4
<i>Diplodus vulgaris</i>	Dvul	4	0	155.3	0.0	<b><i>Symphodus bailloni</i></b>	<b>Sbai</b>	<b>93</b>	<b>159</b>	<b>1,421.3</b>	<b>1,417.5</b>
<i>Pleuronectes platessa</i>	Ppla	1	0	0.1	0.0	<i>Symphodus cinereus</i>	Scin	1	1	51.5	4.3
<i>Scophthalmus rhombus</i>	Srho	0	3	0.0	18.7	<i>Trachurus trachurus</i>	Ttra	8	5	112.3	56.3
<i>Solea senegalensis</i>	Ssen	6	0	96.0	0.0	Catadromous Migrant Species					
<i>Solea solea</i>	Ssol	3	0	41.6	0.0	<b><i>Anguilla anguilla</i></b>	<b>Aang</b>	<b>53</b>	<b>46</b>	<b>2,690.2</b>	<b>2,031.8</b>
<i>Spondyliosa cantharus</i>	Scan	1	0	89.2	0.0	Anadromous Migrant Species					
<i>Trisopterus luscus</i>	Tlus	4	0	10.4	0.0	<i>Alosa alosa</i>	Aalo	4	3	287.1	57.5
Marine Seasonal Migrant Species						<i>Alosa fallax</i>	Afal	21	24	551.2	344.1
<i>Chelon labrosus</i>	Clab	140	14	1,846.2	757.4	<i>Gasterosteus aculeatus</i>	Gacu	0	13	0.0	182.5
<i>Ciliata mustela</i>	Cmus	22	6	139.3	212.6	<b><i>Liza ramada</i></b>	<b>Lram</b>	<b>627</b>	<b>1,227</b>	<b>10,587.2</b>	<b>11,375.7</b>
<i>Engraulis encrasicolus</i>	Eenc	352	334	359.6	715.4	<b><i>Liza saliens</i></b>	<b>Lsal</b>	<b>444</b>	<b>10</b>	<b>6,270.6</b>	<b>267.1</b>
<b><i>Liza aurata</i></b>	<b>Laur</b>	<b>4,273</b>	<b>5,092</b>	<b>45,624.5</b>	<b>50,237.4</b>						
<b><i>Sardina pilchardus</i></b>	<b>Spil</b>	<b>8,739</b>	<b>9,478</b>	<b>13,683.9</b>	<b>13,694.3</b>						



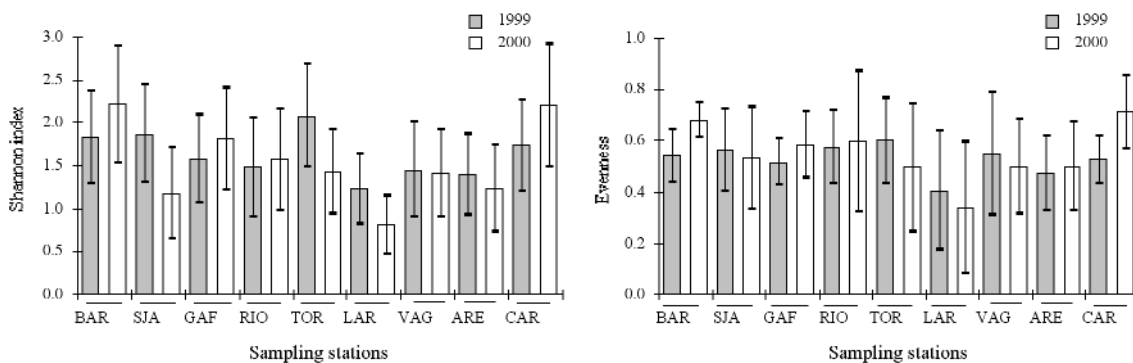
**Figure 4.** Species richness variation  $\pm$  S.E., per month and sampling site.

**Figure 4.** Variation de l'abondance spécifique  $\pm$  SE, par mois et par site d'échantillonnage.



**Figure 5.** Shannon and Evenness indices variation  $\pm$  S.E., per sampling months, in biomass for each year.

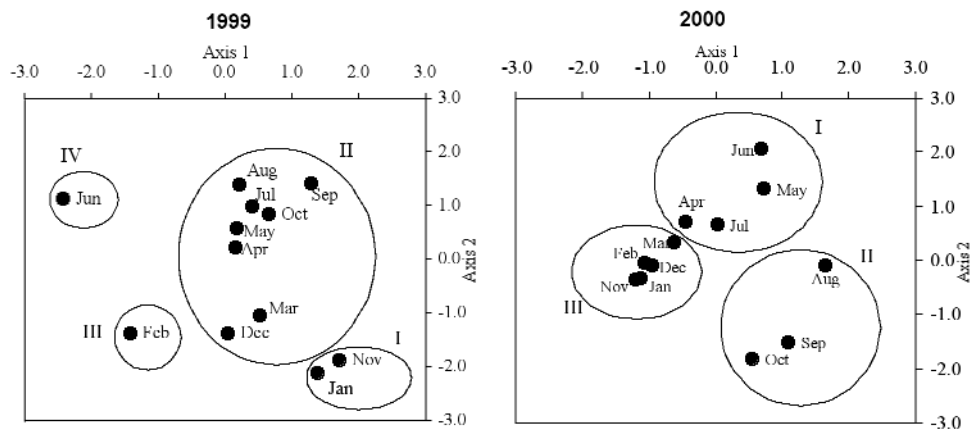
**Figure 5.** Variation de l'indice de Shannon et de la régularité  $\pm$  S.E., par mois d'échantillonnage, en biomasse pour chaque année.



**Figure 6.** Shannon and Evenness indices variation  $\pm$  S.E., per sampling sites, in biomass for each year.

**Figure 6.** Variation de l'indice de Shannon et de la régularité  $\pm$  S.E., par site d'échantillonnage et en biomasse pour chaque année.



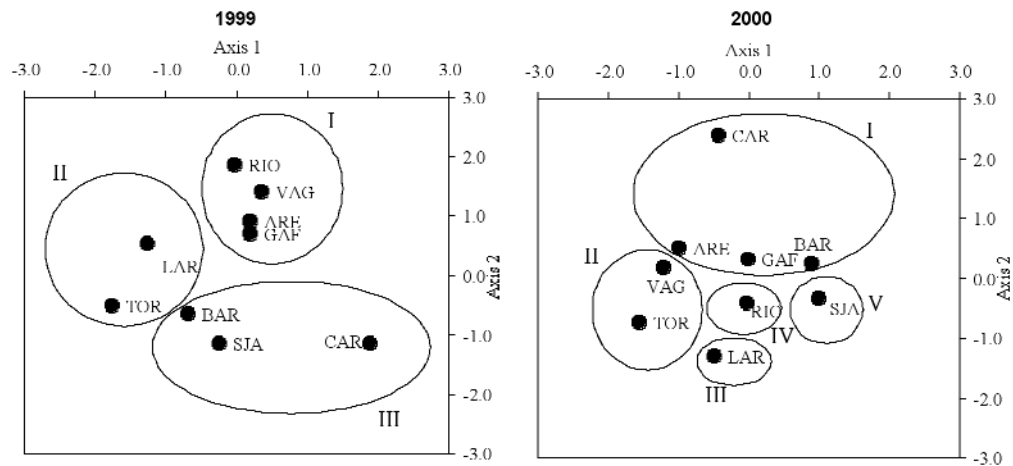


**Figure 7.** Multi-dimensional scaling (MDS) ordination of fish biomass collected in each sampling month for each year. Clusters are produced after Bray-Curtis similarity analyses (55% of similarity are the levels of which each fusion occurs). Axis 1 and 2 accounted for 30% and 25% of the variability explained, respectively, in 1999, and for 45% and 29% in 2000.

**Figure 7.** Ordination multidimensionnelle par MDS de la biomasse des poissons récoltés chaque mois pour chaque année. Les groupes sont issus de l'analyse de similarité de Bray-Curtiss (groupement à 55% de similarité). Les axes 1 et 2 représentent respectivement 30% et 25% de la variabilité en 1999, 45% et 29% en 2000.

There were no statistically significant interactions between months, sites, and years in the species richness. Species richness was significantly higher in 1999 than in 2000 ( $p = 0.003$ ), but in both years the number of species was consistently higher in spring-summer (from March to September ranging from 15 to 28 species) than in autumn-

winter (from October to February ranging from 14 to 23 species) (Fig. 4). The increase in the number of species in spring and summer could be attributed to an influx of marine seasonal migrant species and marine juvenile species. Spatially, species richness showed no regular trend related to distance from the entrance of the lagoon (Fig.4) and was



**Figure 8.** Multi-dimensional scaling (MDS) ordination of fish biomass collected in each sampling site for each year. Clusters are produced after Bray-Curtis similarity analyses (52% of similarity are the levels of which each fusion occurs). Axis 1 and 2 accounted for 33% and 29% of the variability explained, respectively, in 1999, and for 41% and 25% in 2000.

**Figure 8.** Ordination multidimensionnelle par MDS de la biomasse des poissons récoltés par site pour chaque année. Les groupes sont issus de l'analyse de similarité de Bray-Curtiss (groupement à 52 % de similarité). Les axes 1 et 2 représentent respectivement 33% et 29% de la variabilité en 1999, 41% et 25% en 2000.

higher in 2000 only at three sampling sites (GAF, RIO and VAG) mostly due to the influx of marine adventitious species, but also marine seasonal species.

The indices of Shannon-Wiener diversity and evenness, determined based on biomass, showed similar seasonal and spatial patterns each year during the study period (Figs. 5 and 6). Any interactions between months, sites, and years showed no significant difference in the Shannon-Wiener diversity and evenness indices. The indices, while showing similar seasonal patterns, were significantly different between years ( $p = 0.008$  for Shannon-Wiener,  $p = 0.012$  for evenness), with 1999 being higher than 2000 (Figs. 5 and 6). Spatially, the Shannon-Wiener diversity and evenness were not significantly different between years at any sites. Shannon-Wiener diversity and evenness were higher in spring and autumn, and were lower in November and February of 2000 and June of 1999 (Fig. 5). These periods corresponded to the large recruitment of adult marine seasonal migrant and marine adventitious species, with high biomass, resulting in the lowest values of the diversity index and evenness. Spatially, diversity and evenness were higher at intermediate regions and the regions near the mouth of the lagoon in 1999, and at the northern site in 2000 (Fig. 6), where the occurrence of adult *L. ramada* and *L. aurata* was high.

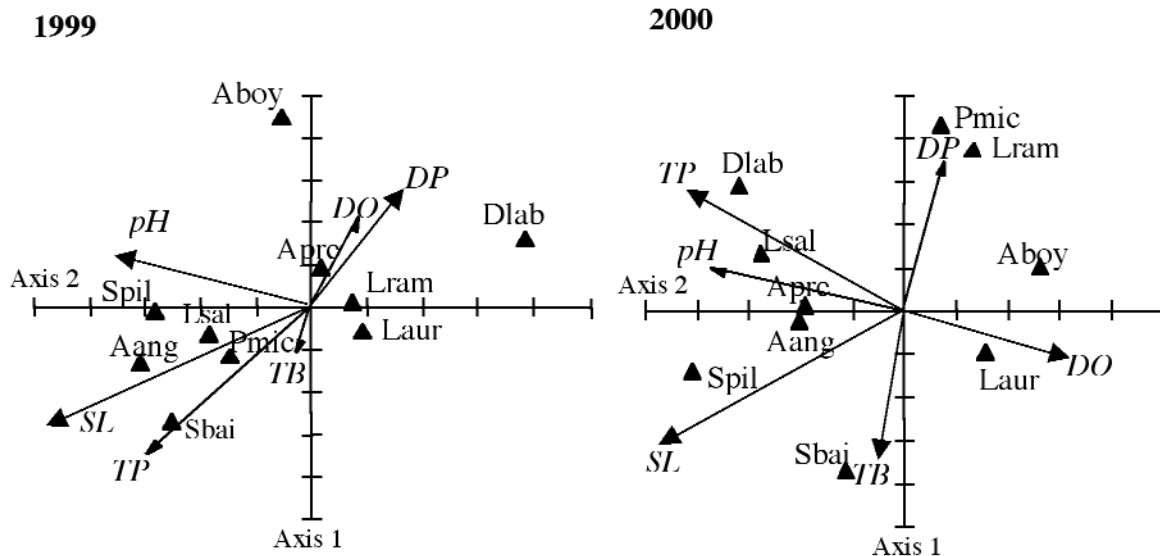
The MDS ordination and cluster analyses showed that the fish assemblages were distinct between cooler, intermediate and warmer seasons (Fig. 7). Fish biomass collected

from the cooler seasons were positioned on the right lower (in 1999) and left (in 2000) of the MDS 2-dimensional plot, and those collected from the warmer seasons were positioned on the left of the plot (in 1999) and in the mid-upper (in 2000), and from the intermediate seasons were positioned in the middle of the plot.

The dominant axis 1, which accounted for 30% in 1999 and 45% in 2000 of the observed variation by all axes, had an eigenvalue of 0.25 in 1999 and 0.37 in 2000 and separated the groups seasonally, while axis 2 had an eigenvalue of only 0.18 in 1999 and 0.19 in 2000 and accounted for 25% in 1999 and 29% in 2000 of the four axes. Axes 3 and 4 accounted for little of the remaining variation and were not assessed further.

For the site groupings determined from the MDS ordination (Fig. 8), fish biomass collected from the edges were positioned on the right (in 1999) and mid-upper (in 2000) of the plot, and those collected from the inner sites were positioned on the left of the plot (in 1999) and in the mid-lower (in 2000), whereas those from the mouth of the lagoon were positioned in the mid-lower (in 1999) and in the right side (in 2000).

The classification of the monthly biomass samples distinguished four groups in 1999 and three groups in 2000 at the 55% level of Bray-Curtis similarity. Over the whole year there was a diverse assemblage, dominated by either *L. aurata* (more than 45%, cluster I, and II) or *S. pilchardus* (60% in



**Figure 9.** CCA ordination diagram of Ria de Aveiro dominant fish biomass with environmental factors represented by vectors: temperature (TP); salinity (SL); dissolved oxygen (DO); pH (pH); turbidity (TB) and depth (DP). Species code names are provided in table 2. Axis 1 and 2 accounted for 42% and 30% of the variability explained, respectively, in 1999, and for 50% and 31% in 2000.

**Figure 9.** Diagramme d'ordination de l'Analyse Canonique des Correspondances (ACC) de la biomasse des poissons dominants de Ria de Aveiro en relation avec les facteurs environnementaux représentés par des vecteurs : température (TP), salinité (SL), oxygène dissous (DO) ; pH (pH) ; turbidité (TB) et profondeur (DP). Les noms de code des espèces sont notés dans le tableau 2. Les axes 1 et 2 représentent respectivement 42% et 30% de la variabilité expliquée en 1999, 50% et 31% en 2000.

**Tableau 3.** The degree of correlation between species richness and diversity indices (Shannon index & Evenness, using fish biomass data) and abiotic factors. TP: temperature; SL: salinity; DO: dissolved oxygen; pH: pH; TB: turbidity; DP: depth (n.s.):  $p > 0.05$ ; (+ or -):  $0.05 > p > 0.01$ ; (++) or (--):  $0.01 > p > 0.001$ ; (+++) or (---):  $p < 0.001$ .

**Tableau 3.** Degré de corrélation entre l'abondance spécifique et les indices de diversité (indice de Shannon et régularité, utilisant la biomasse de poissons) et les facteurs abiotiques. TP : température ; SL : salinité ; DO : oxygène dissous ; pH : pH ; TB : turbidité ; DP : profondeur (n.s.) :  $p > 0,05$ ; (+ ou -):  $0,05 > p > 0,01$ ; (++) ou (--):  $0,01 > p > 0,001$ ; (+++ ou ---):  $p < 0,001$ .

	1999						2000					
	TP	SL	DO	pH	TB	DP	TP	SL	DO	pH	TB	DP
Species Richness	++	+++	n.s.	++	n.s.	---	+++	+++	++	++	n.s.	-
Shannon index	+	+++	n.s.	+	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.
Evenness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

the cluster IV) (fig. 7). The February assemblage (cluster III) was dominated by *A. boyeri* (26%) with large components of *L. aurata* (25%) and also *S. pilchardus* (25%).

Cluster analysis of species biomass data from the different sites distinguished three groups in 1999 and five groups in 2000 at the 52% level of Bray-Curtis similarity (fig. 8). In 1999, the assemblages I and II were strongly dominated by *L. aurata* (48% in cluster I and 55% in cluster II). Both represented assemblages of moderate to high abundance and diversity. Assemblage III was dominated by other secondary components (33%), *S. pilchardus* (27%) and *L. aurata* (24%), representing the largest group of individuals (10893) and a high diversity of species. The biomass assemblage in 2000 varied considerably, but the largest component was usually *L. aurata* (clusters I, II and III). Assemblage IV was unusual in its dominance of *D. labrax* (47%), representing the smallest number of individuals (1134 samples). In comparison, assemblage V was the largest, dominated by *S. pilchardus* (57%) and displayed a high diversity.

#### Environmental Influences on Fish Distribution

The relative importance of the measured environmental factors to the dominant fish biomass is shown in figure 9 (as determined by the environmental variable vectors within the canonical correspondence analyses). Although four axes were determined within each analysis, only axes 1 and 2 were plotted as they accounted for 72% and 81% of the variability explained by the four axes, respectively in each year.

The relative lengths of the vectors indicate that salinity was found to be the most important abiotic factor explaining the fish biomass, with temperature also explaining some of the distribution of fish biomass being positively correlating with Shannon-Weiner index (Table 3). Biomass of dominant species was higher in summer, near the mouth of the lagoon, in the middle of the main channel and the inner channel, where high salinity levels occurred (Figs. 3

and 4). Salinity and temperature positively correlated to *S. pilchardus* and *A. anguilla* in both years (fig. 9), which occurred with high biomass near the mouth of the lagoon and in the middle of the main channel with high salinity, especially in summer, with high temperature.

The nature of CCA dictates that any species highly correlated with two variables will be positioned along the axis created by two vectors rather than at the end of any single vector (Ter Braak, 1988). Thus, the positions of depth, turbidity, and dissolved oxygen vectors may result in a skewing of the species distribution.

## Discussion

Fish studies are important in estuarine water quality evaluation and assessments of human impacts (Elliott et al., 1988; Elliott & Hemingway, 2002) and both fish biomass and species diversity can provide managers with an indication of the health of a particular system (Whitfield, 1996). They indicate the nature of the area, the effects of anthropogenic influences and the efficacy of management actions although an interpretation of these aspects requires a knowledge of the fish biology in relation to environmental changes. This is particularly true of highly variable systems such as the Ria de Aveiro in which, as shown here and elsewhere, the distribution and biomass of fish was related to three broad factors: life-history patterns, environmental variation, particularly water salinity and temperature, and variation in habitat characteristics (depth).

#### Life History Patterns

The estuarine coastal lagoon, Ria de Aveiro, comprises the usual components of an estuarine fish assemblage, including residents, nursery, and seasonal, juvenile and diadromous migratory types. According to the definition of estuarine resident species and marine juvenile migrant

species (Elliott & Dewailly, 1995), *A. boyeri* and *P. microps*, which were confined to the inner region and edges of the lagoon, were considered to be estuarine dependent during all their life cycle. The species, *A. presbyter* and *D. labrax*, were considered estuarine dependent only in the juvenile phase, and marine seasonal species included juveniles of *S. pilchardus* and *L. aurata*. Because these estuarine opportunistic species are found at various times throughout the lagoon systems, they are considered to be appropriate indicators of natural or anthropogenic change in lagoons and estuaries (Pombo & Rebelo, 2002). Although the number of marine seasonal species was low, their biomass were very high. The opposite occurred with the marine adventitious species with high number of species but low biomass, hence the term adventitious. Diadromous (catadromous or anadromous) migrant species, which use the lagoon to pass between salt and freshwater for spawning and feeding, included *A. Anguilla* (a traditional and economically important species for the region), *L. ramada* and *L. saliens* (some of the largest collected specimens). Freshwater species, which were very rare, entered occasionally to the lagoon with no apparent estuarine requirements.

#### *Relationships between Environment and Fish Assemblages*

The Ria de Aveiro, similar to other coastal estuarine lagoons (Leeuwen et al., 1994; Elliott & Hemingway, 2002), is a system highly influenced by abiotic variations, which affects the recruitment and the survival of fish species (Rebelo, 1992; Pombo & Rebelo, 2002). Salinity was found to be the most important abiotic factor affecting the biomass and distribution of fish species and proved to be the best predictor of total biomass, with temperature also having a major influence. Variation in biomass within the lagoon was more related to seasonal migrations rather than to spatial migrations within the lagoon. Similar results have been observed in other regions of the world (Thiel et al., 1995; Jones et al., 1996; Marshall & Elliott, 1998; Kuo et al., 2001).

The ichthyofauna of the lagoon varied in response to temperature, with major differences observed between spring-summer and autumn-winter. For the warmer spring-summer period, where average temperatures were above 15°C, the fish biomass was high over the whole lagoon. During the cooler autumn-winter period, most of the dominant species decreased in biomass markedly and occurred in greater abundance and biomass at the areas near the mouth of the lagoon. This was particularly the case for the adventitious and seasonal migrant species.

The variation in species diversity was mainly due to the frequently occurring species, those abundant species which are characteristic of the lagoon, and are responsible for the fish productivity of this lagoon system. Although the biomass (113 and 110 Kg wet weight, respectively in each

year) was similar in both years, the abundance was slightly higher in the second year (19,424 and 22,257 individuals in the first and second year, respectively). This is due to the large migration into the lagoon of juvenile (small individuals with a low biomass) of *S. pilchardus*. These small juveniles however did not result in a high total biomass.

Many studies (Thorman, 1986; Thiel et al., 1995; Marshall & Elliott, 1998) have indicated that salinity is an important factor in influencing the distribution and abundance of fish in estuaries, particularly those with significant freshwater influx (Loneragan & Potter, 1990). In the present study and in the Humber estuary (Marshall & Elliott, 1998) variation in temperature and salinity was related to variation in different aspects of the fish community, with more species apparently affected by salinity changes than temperature variation. Salinity significantly varied seasonally and spatially between 0 and 35, decreasing gradually towards the upper reaches of the channels with a significant freshwater inflow, but in some remote shallow areas the circulation was reduced and increased salt concentration occurred during summer. The lack of statistical interactions between sites and months indicates that much of the variations appeared related to seasonal climate cycles, such as rainfall. At times of maximum freshwater discharge resulting from continued rainy periods, as occurred in 2000, the salinity decreased significantly all over the lagoon.

The biomass distributions were affected by the movements of fish within the lagoon. These migrations modified the distribution of the ichthyofauna, especially the benthic fish, which migrate to deeper regions, possibly as a strategy for protection against predators and to minimize food competition with others fish species (Harlay et al., 2001). The low salinity, particularly between March and May, due to the continued rainy periods in the second year of sampling, will influence the distribution of fish mainly through their salinity tolerance. Thus, in some cases, low salinity may act as a barrier to penetration by stenohaline marine species; therefore the number of species was much lower in the second year of sampling during the reduced salinity periods. Similar patterns were observed in the Bothnian Sea (Thorman, 1986) with positive correlations between minimum salinity and average species number. However, in many cases, the range of salinity at which fish are habitually found is much narrower than their tolerance range. In addition, the response of many species to salinity may vary with life stage (Kuo et al., 2001).

Correlations between the other environmental factors and assemblage structure were identified. Dissolved oxygen showed a similar trend to salinity also importantly explaining variation in the distribution of fish species; it is of note that water quality barriers, through the production of low oxygen zones, have influenced community structure in many estuarine areas (Elliott & Hemingway, 2002) and

low levels could affect the species composition through the tolerance limits of the different species. Dissolved oxygen and depth influenced most species in the second year, when both factors decreased.

The relationship between pH and biomass of *A. anguilla* was strong in the first year but, when pH significantly increased in the second year, the relationship was not significant. In the first year, this species occurred mainly in the main channel, where pH was basic-alkaline but in the second year, when the pH values increased in the lagoon, the species moved towards the mouth, where more alkaline values persisted. The interactions between month and year for pH factor, and between site and year for the depth factor, indicate that these two parameters may have an important influence on fish assemblage. Species richness was positively correlated with pH, while depth was negatively correlated with species richness. However, it is possible that these correlations are due to co-variance with third factors such as salinity (freshwater discharge).

The importance of turbidity has been attributed to providing either protection from visual predators or an increased food supply (Marshall & Elliott, 1998). In this study, turbidity did not have a significant relationship with species richness or diversity indices. This is evident in the CCA plot, where the turbidity vector was the smallest.

This study constitutes a baseline for future studies both within the lagoon and elsewhere in transitional water bodies. In particular, it shows the importance of showing the inter-relationships between the biotic (fish) and abiotic factors. Although it is difficult to separate and analyse separately each environmental factor from the others, it is known that they interact with each other. There are other environmental factors that were not monitored in this study and that are likely to have an influence on fish distribution, namely the tides, current velocity, streams, and human impacts, as fishing (Marshall & Elliott, 1996, 1998). Several natural and anthropogenic factors may have a direct influence on the environmental and therefore on food resources, distribution, abundance, growth, survival and behaviour of the fish present (Whitfield, 1996). In addition, for a complete understanding of lagoonal fish ecology, it is necessary to determine the biological relationships superimposed on those environmental relationships, for example predator-prey and competition interactions.

In recent decades, there has been an increasing concern about man's impact on the ecosystem (Van Leeuwen et al., 1994). The marine environment may potentially be affected by a variety of human activities, both direct and indirect, including coastal engineering works, pollution, eutrophication, fisheries and global warming. Dredging of the Ria de Aveiro occurred in the years prior to this study (between October 1997 and May 1998) and included extracting a total of 1,510,000 m<sup>3</sup> of sediment from the main channels

(Ovar, Murtosa, and Mira) (JAPA, 1993). This increased the tidal-range and water exchange (JAPA, 1993), possibly allowing a large variety of marine adventitious species to enter the lagoon. In particular, deepening of channels may provide greater potential for water column species (JAPA, 1993), particularly marine species, to enter from the adjacent coastal zone.

Other possible indirect factors such as fluctuations in tide levels, current velocity and direction may influence the fish communities (Jones et al., 1996). The aggregation of lagoon-opportunistic and lagoon-dependent species in smaller areas may increase vulnerability of populations to a number of environmental and human perturbations such as point-source pollution (organic and chemical spills), toxic algal blooms or seasonally heavy fishing intensity (Jones et al., 1996). However, the relatively high levels of oxygen and the presence of a varied ichthyofauna indicate that the adopted environmental quality objectives (EQO) are being fulfilled (Marshall & Elliott, 1996).

The increasing fishing effort as a result of the leisure and commercial fishing has suggested that it has increased for some species, mainly *Solea solea*, *Platichthys flesus*, *A. anguilla* and *D. labrax*. Another consequence of fishing is a decrease in the potential nursery area for estuary-opportunistic species in the inner estuary during warmer months, so in the years of high recruitment to the lagoon survival rate of new recruits could be adversely affected. It is also possible that a change in the predator-prey relationship may occur in the lagoon affected area. Further studies are required on trophic relationships between species and on production studies to better predict how this factor may influence the fish community structure.

The Ria de Aveiro shows a dynamic and a variable environment, like other transitional water bodies, with significant variations in the abiotic and physical parameters of the water. These environmental variations appear to have an important influence on the distribution and diversity of the ichthyofauna, with strong seasonal patterns observed by our study. Despite the vulnerability of this system, the Ria de Aveiro exhibits a predictable spatial and temporal pattern of fish biomass and diversity.

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## References

- Arruda L.M., Andrade J.P. & Cunha M.M. 1988. Abundance, diversity and community structure of the fish population in the Ria de Aveiro (Portugal). *Oceanologica Acta*, **11**: 235-240.
- Barrosa J.O. 1980. A Ria de Aveiro e a sua influência na economia da região. *Recursos hídricos*, **1**: 83-96.
- Bauchot M.L. & Pras A. 1987. *Guía de los peces de mar de España y de Europa*. Ediciones Ómega: Barcelona, 432 pp.
- Boesch D.F. 1977. Application of numerical classification in ecological investigations of water pollution. Virginia Institute of Marine Science, *Special Science Report* No.77.
- Borrego C., Cruz M.M. & Gonçalves P. 1994. *Estudo de avaliação da vulnerabilidade da capacidade de recepção das águas costeiras em Portugal. Relatório R 3.2. Meios receptores e suas características: (Be 1) - Ria de Aveiro, Pateira de Fermentelos e Barrinha de Mira*. Projecto nº 13/94. IDAD: Aveiro. 69 pp.
- Elliott M. & Dewailly F. 1995. The structure and components of European estuarine fish assemblages. *Netherlands Journal of Aquatic Ecology*, **29**: 397-417.
- Elliott M., Griffiths A.H. & Taylor C.J.L. 1988. The role of fish studies in estuarine pollution assessment. *Journal of Fish Biology* **33** (Supplement A): 51-61.
- Elliott M. & Hemingway K.L. (Eds.) 2002. *Fishes in Estuaries*. Blackwell Science: Oxford. 636 pp.
- Hall A. 1980. Water quality problems in Ria de Aveiro. A preliminary assessment. In: *Seminar on actual problems of Oceanography in Portugal, 20-21 de Novembro*, pp. 159-169. Lisboa.
- Harlay X., Koubbi P. & Grioche A. 2001. Ecology of plaice (*Pleuronectes platessa*) in fish assemblages of beaches of the Opale coast (North of France) during spring 1977. *Cybiurn*, **25**: 67-80.
- Hill M.O. 1973. Diversity and evenness: A unifying notation and its consequences. *Ecologie*, **54**: 427-432.
- James, E.M. Jr. 2001. Biological structure and dynamics of littoral fish assemblages in the Eastern Finger Lakes. *Aquatic Ecosystem Health and Management Society*, **4**: 91-115.
- JAPA. 1993. *Estudo de impacto ambiental – desassoreamento da Ria de Aveiro, 1ª fase*. Junta Autónoma do Porto de Aveiro. Edição do Porto de Aveiro: Aveiro.
- Jones G.K., Baker J.L., Edyvane K. & Wright G.J. 1996. Nearshore fish community of the Port River-Baker Inlet Estuary, South Australia. I. Effect of the thermal effluent on the fish community structure, and distribution and growth of economically important fish species. *Marine Freshwater Research*, **47**: 785-99.
- Jongman R. H. G., ter Braak C. J. F. & van Tongeren O. F. R. 1995. *Data analysis in community and landscape ecology. Ch. 5 Ordination*. Cambridge University Press: New York.
- Karr J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries*, **6**: 21-27.
- Kovack. 1998. *MVSP version 3.01*. Copyright Kovack Computing Services: U.K.
- Kuo S-R., Lin H-J. & Shao K-T. 2001. Seasonal changes in abundance and composition of the fish assemblage in Chiku lagoon, Southwestern Taiwan. *Bulletin of Marine Science*, **68**: 85-99.
- Leeuwen P. I. van, Rijnsdorp A. D. & Vingerhoed B. 1994. Variations in abundance and distribution of demersal fish species in the coastal zone of the Southeastern North Sea between 1980 and 1993. *Demersal Fish Committee*, **10**: 1-19.
- Lima C. 1986. Impacto da poluição por mercúrio nos organismos aquáticos da Ria de Aveiro. *Relatórios do Instituto Nacional Investigaciones Pescas*, **66**: 1-28.
- Loneragan N.R. & Potter I.C. 1990. Factors influencing community structure and distribution of different life-cycle categories of fishes in shallow waters in a large Australian estuary. *Marine Biology*, **106**: 25-37.
- Lucas M.F., Caldeira M.T., Hall A., Duarte A.C. & Lima C. 1986. Distribution of mercury in the sediments and fishes of the lagoon of Aveiro, Portugal. *Water Science and Technology*, **18**: 141-148.
- Ludwig J.A. & Reynolds J.F. 1988. *Statistical Ecology. A primer on methods and computing*. Wiley-Interscience Publications: New York, Chichester, Brisbane, Toronto, Syngapore. 337 pp.
- Marshall S. & Elliott M. 1996. The structure of the fish assemblage in the Humber Estuary, U.K. *Publicaciones Especiales. Instituto Espanol de Oceanografia*, **21**: 231-242.
- Marshall S. & Elliott M. 1998. Environmental influences on the fish assemblage of the Humber Estuary, UK. *Estuarine, Coastal and Shelf Science*, **46**: 175-184.
- Matthews W.J. 1998. Diel differences in gillnet and seine catches of fish in winter in a cove of Lake Texoma, Oklahoma – Texas. *Texas Journal of Science*, **38**: 153-158.
- Nobre A., Afreixo J. & Macedo J. 1915. *A Ria de Aveiro, Relatório oficial do regulamento da Ria de 28 de Dezembro de 1912*. Imprensa Nacional: Lisboa, 197 pp.
- Osório B. 1912. Pescas e peixes. Uma nota relativa à pesca e aos peixes da Ria de Aveiro. *Boletim da Sociedade Geografica. Lisboa*, **30**: 216-224.
- Pombo L. & Rebelo J.E. 2000. Ria de Aveiro ictiofauna: diversity in space and time. *Revista de Biologia (Lisboa)*, **18**: 69-81.
- Pombo L. & Rebelo J.E. 2002. Spatial and temporal organisation of a coastal lagoon fish community, Ria de Aveiro, Portugal. *Cybiurn*, **26**: 185-196.
- Pombo L., Borges R., Rebelo J.E., Duarte A.C. & Bóia C. 2000. Níveis de mercúrio no músculo de peixes (especialmente robalo, *Dicentrarchus labrax*, LINNAEUS, 1758) capturados no meio natural e em pisciculturas da Ria de Aveiro. Estudos de Biogeoquímica na Zona Costeira Ibérica. In: *IX Seminário Ibérico de Química Marinha*, pp. 251-259. Aveiro.
- Pombo L., Elliott M. & Rebelo J.E. 2002. Changes in the fish fauna of the Ria de Aveiro estuarine lagoon (Portugal) during the twentieth century. *Journal of Fish Biology*, **61** (Supplement A): 167-181.
- Rakocinski C. F., Lyczkowski-Shultz J. & Richardson S.L. 1996. Ichthyoplankton Assemblage structure in Mississippi Sound as revealed by canonical correspondence analysis. *Estuarine, Coastal and Shelf Science*, **43**: 237-257.
- Rebelo J. E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries*, **15**: 403-415.
- Rogers S.G., Targett T.E. & van Sant S.B. 1984. Fish nursery use in Georgia salt-marsh estuaries: the influence of springtime

- freshwater conditions. *Transactions of the American Fisheries Society*, **113**: 595-606.
- Shannon C.E. & Weaver W. 1949.** *The mathematical theory of communication*. University of Illinois Press: Urbana, IL.
- Sokal R. R. & Rohlf J. F. 1995.** *Biometry*. W.H.Freeman and company: New York. 3<sup>rd</sup> ed. 887 pp.
- Ter Braak, C. J. F. 1988.** *Canoco-a Fortran program for Canonical Community Ordination*. Microcomputer Power. Ithaca: New York. 95 pp.
- Thiel R., Sepulveda A., Kageman R. & Nellen W. 1995.** Environmental factors as forces structuring the fish community of the Elbe estuary. *Journal of Fish Biology*, **46**: 47-69.
- Thorman S. 1986.** Seasonal colonization and effects of salinity and temperature on species richness and abundance of fish of some brackish and estuarine shallow waters in Sweden. *Holarctic Ecology*, **9**: 126-132.
- Whitehead P. J. P., Bauchot M.-L., Hureau J.-C., Nielsen J. & Tortonese E. 1986.** *Fishes of the North-eastern Atlantic and the Mediterranean*. 3 vols. UNESCO: U.K. 1984 pp.
- Whitfield A.K. 1996.** Fishes and the environmental status of South African estuaries. *Fisheries Management and Ecology*, **3**: 45-57.
- Zar J. H. 1984.** *Biostatistical Analysis*. Prentice-Hall, Inc., 2<sup>nd</sup> ed.: New Jersey. 718 pp.