# DEPARTAMENTO DE ZOOLOGIA

FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE DE COIMBRA


# The impact of climatic instability in the fish assemblage of the Mondego Estuary (Portugal)

Dissertação apresentada à Universidade de Coimbra para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Ecologia, realizada sob a orientação científica do Professor Doutor Miguel Ângelo Pardal (Universidade de Coimbra) e do Professor Doutor Henrique Cabral (Universidade de Lisboa)


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## Resumo

O estudo da comunidade de peixes no estuário do Mondego (Portugal) ocorreu desde Junho de 2003 até Março de 2008. As amostragens foram efectuadas mensalmente em cinco estações de amostragem e durante a noite. Segundo as condições climáticas, foram definidos dois períodos: anos regulares (desde Junho 2003 até Maio de 2004 e Junho de 2006 até Maio de 2007) e anos secos (Junho de 2004 até Maio de 2005, Junho de 2005 até Maio de 2006 e Junho de 2007 até Março de 2008). A comunidade de peixes foi analisada segundo seis guilds ecológicos, dados de presença/ausência e de abundância. A riqueza específica variou entre 36 espécies pertencentes a 20 famílias, nos anos regulares, e 38 espécies pertencentes a 20 famílias, nos anos secos. A densidade da comunidade foi mais elevada nos regulares do que nos anos secos. Os dois períodos foram considerados diferentes. Os anos regulares estavam associados a uma precipitação e escoamento mais elevado e valores de salinidade mais baixos nos locais mais a montante do estuário, enquanto que os anos secos foram caracterizados por elevados valores de salinidade por todo o estuário. Os anos secos estavam mais associados a espécies marinhas, consequentemente neste período novas espécies marinhas foram encontradas no estuário, e as espécies de água doce desapareceram completamente. Nos anos secos a densidade dos indivíduos que usam o estuário como zona de viveiro diminuiu. A estrutura e composição da comunidade de peixes foram influenciadas por um gradiente salínico. As espécies marinhas apareceram, principalmente, nas zonas mais a jusante, enquanto que as espécies que usam o estuário como zona de viveiro apareceram, principalmente, nas zonas mais a montante. No que respeita as espécies que usam o estuário como zona de viveiro e as espécies residentes estuarinas, os principais componentes da comunidade de peixes do estuário do

Mondego, foi registado um decréscimo geral na abundância, que evidência a influência negativa da redução do escoamento.

## Abstract

The study of the fish assemblage in the Mondego estuary (Portugal) was carried out from June 2003 to March 2008. Sampling was carried out monthly at five stations and during the night. According to the weather conditions, it was defined two distinct periods: regular years (from June 2003 to May 2004 and from June 2006 to May 2007) and dry years (June 2004 to May 2005, June 2005 to May 2006 and June 2007 to March 2008). The fish community was analysed according to six ecological guilds, presence/absence and abundance data. The species richness varied between 36 species from 23 families, in the regular years, and 38 species from 20 families, in the dry years. In general, the estuarine salinity gradient influenced the structure and composition of the fish community, with marine species appearing mostly at the downstream areas, while the nursery species appeared mostly at the upstream areas. Fish densities were higher in the regular years than the dry years. The two periods were considered different. The regular period was associated with higher precipitation and freshwater runoff and lower salinity values at the upstream areas of the estuary, whereas the dry period was characterized by higher salinity values thorough the estuary. The dry years were associated with more marine species, due to the higher salinity incursion, and therefore in this period new marine species were found in the estuary, and the freshwater adventitious species completely disappeared. In the dry years nursery species decreased in density. Regarding the nursery and resident species, the main components of the Mondego estuary fish community, it was recorded a general decrease in abundance, which can point out the negative influence of the reduction in freshwater flow.

# Contents

# Chapter 1

# Introduction

Estuaries are among the most productive systems, being recognized by their biological importance and utilization by humans. (Harrison and Whitfield, 2006; Vasconcelos et al., 2007). They are known for their high productive levels, due to the increase of available nutrients and abundance of primary resources (Edgar and Shaw, 1995; Pombo et al., 2007; Dolbeth et al., 2008a). However, estuaries are located in human-populated areas leading to high human activities and their effects, such as eutrophication, dredging activities, general organic pollution (Chícharo et al., 2006; Dolbeth et al., 2007a; Martinho et al., 2007a; Ribeiro et al., 2007), habitat reclamation (due to port activities, aquaculture and agriculture) and fishing activities (Dolbeth et al., 2007a).

Estuaries are of particular importance for fish and fisheries (Prista et al., 2003), since some species (marine and freshwater) that enter estuarine waters have important commercial value (Vinagre et al., 2007). As a consequence, estuaries can be considered as essential ecosystems for the restitution of fisheries resources (Dolbeth et al., 2008a). In addition, estuarine environments provide important nursery grounds for marine fish (Cabral et al., 2007; Martinho et al., 2007b), as well as overwintering areas and migration routes, due to the existence of sheltered areas (Beck et al., 2001; Leitão et al., 2007**)** and high prey availability, thus providing refuge against predators and a good environment for the growth and survival of young fishes. Regarding fish, estuaries are also recognized by their relatively low species diversity, despite of the high abundance of the individual taxa (Martinho et al., 2007a).

Assemblages are groups of species that tend to co-occur together, due to similar habitat preferences or because they interact biologically. Species assemblages have been considered as appropriate indicators of habitat heterogeneity, characterizing a particular section of the environmental gradient. Given that estuaries are transition areas, with strong environmental gradients, some species restricted to a particular area, hence demonstrating a zonation pattern (Jaureguizar et al., 2003). The study of ecological interactions between the estuarine fish community is an important feature (Elliott & Dewailly, 1995). According to Elliott & Dewailly (1995) and Elliott et al. (2007), estuarine fish communities can be classified into ecological guilds, representing the biological characteristics of the organisms, and assessing their similarities and dissimilarities. The ecological guilds approach can be used in order to simplify the information, indicating the function of each group of species in the estuarine ecosystem. According to the previous authors, estuarine fish communities can be classified in six ecological guilds: Truly estuarine resident species (ER) – which spend their entire life cycle within the estuary; Marine adventitious visitors (MA) – which appear in the estuary irregularly, although it has no apparent estuarine requirements; Diadromous (catadromous and anadromous) (CA) – migrant species, which use the estuary to pass between sea and freshwater, for spawning and feeding; Marine seasonal migrant species (MS) – which have regular visitors to the estuary, normally as adults; Marine juvenile migrant species (MJ) – which use the estuary as a nursery ground, normally they spawn and spend their adult life at sea, but return seasonally to the estuary; Freshwater adventitious species (FW) – which occasionally enter the estuary, but have no estuarine requirements.

Several studies have reported that the structure and composition of estuarine communities may be affected by climate, and hence hydrodynamics (Marshal and Elliott, 1998; Drake et al., 2002; Harrison and Whitfield, 2006; Costa et al., 2007; Martinho et al., 2007a; Cardoso et al., 2008). Freshwater flow plays an important role in the estuarine dynamics, having a great impact on their physical, chemical and biologic characteristics. The availability of freshwater flow into estuaries can be regulated by human activities and natural environment. In fact, a large number of rivers are regulated by dams, which despite having a negative impact on migratory fishes (Costa et al., 2007), can alter estuarine conditions and hydrodynamics, affecting the natural river flow and also entrance of fishes into the estuary (Vasconcelos et al., 2007). Studying the effects of such hydrological variations, particularly in the long term, is a key issue to cope with the future climate change scenarios, as proposed by the Intergovernmental Panel on Climate Change (2007). Accordingly, the aim of this work was to study the fish assemblage of the Mondego estuary in two distinct periods in terms of hydrology: dry years and regular years, and to assess if such variations in river flow influenced the composition and structure of the estuarine fish community.

# Chapter 2

# Material and Methods

## 2.1. Study site

The Mondego estuary is located in the western coast of Portugal (40º08' N, 8º50' W). It is a small estuary with an area of 6 $Km^2$. The estuary compromises two arms, the north and the south arms, with distinct hydrologic characteristics. The two arms are separated at about 7 Km from the shore and join again near the mouth of the estuary. The north arm is deeper with 5-10 m high tide and 2-3 m tidal range and is frequently dredged to maintain its depth. The south arm is shallower with 2-4 m high tide,1-3 m tidal range and about 75% are intertidal mudflats. The south arm is largely silted up in the upstream areas causing the water to flow mainly through the north arm. The water circulation in the south arm is mainly depending on the tides and on a small input of freshwater of a tributary system, the Pranto River, which is controlled by a sluice, according to the water needs in the rice fields from the Mondego agricultural valley (Martinho et al., 2007a; Leitão et al.,2007; Dolbeth et al.,2008a).

## 2.2. Fish sampling and laboratory work

The fishes were collected monthly, between June 2003 and March 2008, using a 2 m beam trawl, with one thicker chain and 5 mm stretched mesh size in the cod end. Fishing took place during the night, at low water of spring tides, at five stations (M, N1, N2, S1 and S2) (Figure 1). Each survey consisted of three hauls at each sampling station, with an average duration of 3 min each, covering at least an area of 500 $m^2$. Temperature, salinity, pH, dissolved oxygen and depth were measure while fishing took place. All fish caught were counted, identified, measured and weighted.

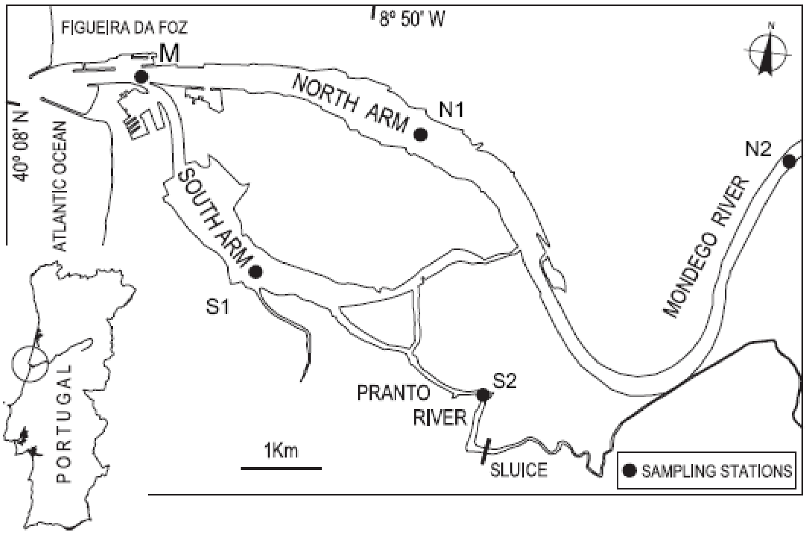


Figure 1. Mondego river estuary, location of the sampling stations.

## 2.3. Data analysis

The fish community was analysed according to two distinct periods: regular years and dry years, according to the reports of the Portuguese Weather Institute (www.meteo.pt). It was considered regular years from June 2003 to May 2004 and from June 2006 to May 2007, and dry years from June from 2004 to May 2005, June 2005 to May 2006 and June 2007 to March 2008. Dry years were characterized by low precipitation, therefore low runoff and an increase in water salinity. Regular years were characterized by high precipitation and runoff, and lower water salinity. Data was analysed according to these two periods in the whole estuary and for each station (M, N1, N2, S1 and S2). Mean values by period (regular and dry) and by season were analysed: summer (from June to August), autumn (from September to November), winter (from December to February) and spring (from March to May). Hydrological data was obtained from INAG – Portuguese Water Institute (http://snirh.inag.pt). Both monthly precipitation and long-term monthly average precipitation were obtained from the Soure 13F/01G station.

Freshwater runoff was acquired from INAG station Açude Ponte Coimbra 12G/01A, near the city of Coimbra (located 40 km upstream).

Species densities were expressed as the number of individuals per 1000m$^2$, and the fish community was analysed according to six ecological guilds, adapted from Elliott and Dewailly (1995), established from habitat pattern usage: marine adventitious species (MA), marine juvenile migrant species (MJ), species that use the estuary as a nursery ground (NU), estuarine resident species (ER), catadromous adventitious species (CA) and freshwater adventitious species (FW).

A t-test for independent variables ($p > 0.05$) was performed to analyse the differences in salinity values between each sampling station, from each period.

To evaluate the differences in the fish community of dry and regular years and their relationship with the environmental variables a distance base redundancy analysis (db-RDA) was performed. For the db-RDA it was used presence/absence data (Jaccard distances) of the twenty more abundant species per season of each period: dry and regular years. All environmental variables were used in a first analysis and their significance was tested with a forwards selection procedure. A second RDA was performed only with the significant environmental variables (precipitation and salinity) for the distribution and composition of fish community. The RDA was chosen after detecting the linear response of the ecological guilds abundances data with the Detrended Correspondence Analysis (DCA). These analyses were performed with CANOCO v 4.5 software.

After detecting differences in the community between dry and regular years, the spatial variations of the fish community per dry and regular year were analysed with non-metric multidimensional scaling (nm-MDS). The differences among sampling stations for each period (dry and regular) were tested with the analysis of similarities

(ANOSIM), for the sampling stations grouped a priori. Pairwise tests confirmed the differences and similarities among sampling stations per season. The similarity percentages (SIMPER) procedure was performed to determine which species contributed most to the similarities observed per sampling station.

# Chapter 3

# Results

## 3.1. Environmental conditions in the Mondego estuary

During the study period (June 2003 to March 2008) precipitation varied between 154mm (±96) and 17mm (±13) (Table I), being highest during the regular autumn and lowest during the regular summer.

Table I. Mean values and standard deviation of precipitation, runoff, salinity, dissolved oxygen, temperature and pH, for each season in each period.

| | Precipitation (mm) | Runoff ($dam^3$) | Salinity | mg/l O2 | Temperature (ºC) | pH |
|---|---|---|---|---|---|---|
| Summer Regular | 17 ± 13 | 38401 ± 13177 | 23.3 ± 4.5 | 7.9 ± 0.8 | 20.7 ± 0.9 | 8.0 ± 0.1 |
| Autumn Regular | 154 ± 96 | 238474 ± 146571 | 18.3 ± 4.2 | 8.3 ± 0.4 | 17.5 ± 0.1 | 7.9 ± 0.04 |
| Winter Regular | 69 ± 39 | 375862 ± 54634 | 20.9 ± 2.2 | 10.2 ± 0.2 | 12.7 ± 1.0 | 7.9 ± 0.2 |
| Spring Regular | 52 ± 21 | 96401 ± 37587 | 22.7 ± 1.2 | 9.3 ± 0.1 | 16.2 ± 1.1 | 7.9 ± 0.3 |
| Summer Dry | 21 ± 24 | 48347 ± 17827 | 26.0 ± 1.8 | 8.0 ± 0.1 | 19.6 ± 1.0 | 7.8 ± 0.3 |
| Autumn Dry | 36 ± 37 | 50799 ± 24839 | 24.5 ± 6.5 | 8.8 ± 0.7 | 14.4 ± 3.0 | 7.8 ± 0.2 |
| Winter Dry | 51 ± 31 | 70609 ± 75667 | 24.9 ± 4.7 | 10.5 ± 1.4 | 11.5 ± 2.3 | 7.8 ± 0.3 |
| Spring Dry | 48 ± 29 | 114492 ± 127686 | 25.1 ± 4.7 | 8.0 ± 1.6 | 17.0 ± 1.9 | 8.2 ± 0.1 |

Mean salinity values were highest during the dry period and lowest during the regular period; the highest value occurred during the dry summer (26), and the lowest value occurred during the regular autumn (18). According to the t-test for independent variables the salinity values for each sampling station were considered different in S1, S2 and N2 (Table II).

Table II. Mean values of salinity per sampling station, for regular years and dry years. * Significative differences for p> 0.05

| | **Salinity** | |
|---|---|---|
| | **Regular years** | **Dry years** |
| **M** | 30.0 ± 7.2 | 31.6 ± 4.9 |
| **S1** | 28.2 ± 6.4 * | 32.2 ± 3.6 * |
| **S2** | 21.8 ± 5.3 * | 27.7 ± 4.9 * |
| **N1** | 20.9 ± 8.1 | 23.4 ± 10.0 |
| **N2** | 3.5 ± 5.5 * | 10.1 ± 7.7 * |

Runoff had highest mean values during the regular winter and lowest mean values during the dry summer. The mean values of water temperature and pH were similar throughout the study period.

Precipitation was higher in October, September and November of 2003, and again in September, October and November of 2006, with values above 200 mm. As a result, freshwater runoff was higher during the subsequent period. In the dry period, precipitation values were almost all below the 1933-2006 average. In 2005, precipitation values were the lowest during the studied period; at this point, the Portuguese territory was in extreme drought (www.meteo.pt) (Figure 2).

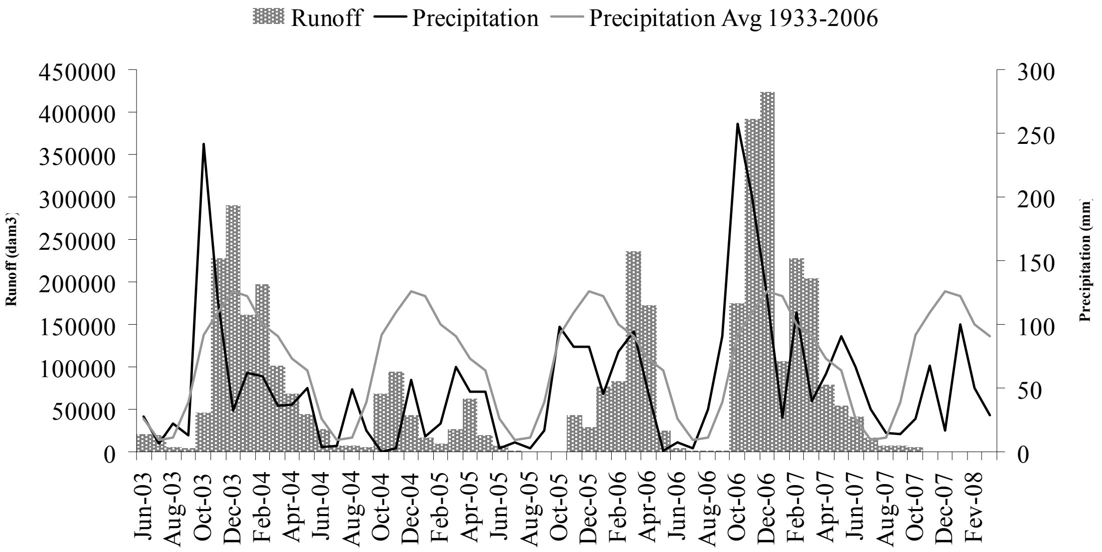


Figure 2. Monthly precipitation and runoff, from June 2003 to March 2008, plotted with the precipitation average of 1933-2006.

### 3.2. Community structure

From June 2003 to March 2008, a total of 42 species, belonging to 23 families were found in the Mondego estuary (Table III). In the regular years, 36 species were found, from 23 families, and belonging to 6 ecological guilds. In the dry years, 38 species were found, from 20 families, and belonging to 5 ecological guilds.

Table III. Mondego estuary fish community for each period: distribution of species according to family, ecological guild (MA – marine adventitious species, MJ – marine juvenile migrant species, NU – species that use the estuary as a nursery ground, ER – estuarine resident species, CA – catadromous species and FW – freshwater adventitious species) and the average of the number of individuals per 1000m$^2$ for each period.

| **Species** | **Family** | **Ecological guild** | **Average N ind 1000m$^{-2}$ regular years** | **Average N ind 1000m$^{-2}$ dry years** |
|---|---|---|---|---|
| *Ammodytes tobianus* | Ammodytidae | MA | 0.45 ± 0.63 | 1.01 ± 1.17 |
| *Anguilla anguilla* | Anguillidae | CA | 6.58 ± 8.85 | 3.05 ± 2.05 |
| *Aphia minuta* | Gobiidae | MA | 0.77 ± 0.98 | 0.16 ± 0.28 |
| *Arnoglossus laterna* | Scophthalmidae | MA | 0 | 0.17 ± 0.15 |
| *Atherina boyeri* | Atherinidae | ER | 3.08 ± 2.01 | 6.86 ± 7.79 |
| *Atherina presbyter* | Atherinidae | ER | 0.28 ± 0.07 | 0.98 ± 0.79 |
| *Barbus bocagei* | Cyprinidae | FW | 0.11 ± 0.16 | 0.00 ± 0.00 |
| *Buglossidium luteum* | Soleidae | MA | 0 | 0.03 ± 0.05 |
| *Callionymus lyra* | Callionymidae | MA | 0.46 ± 0.06 | 1.78 ± 0.76 |
| *Carassius auratus* | Cyprinidae | FW | 0.04 ± 0.06 | 0 |
| *Chelidonichthys lucernus* | Triglidae | MJ | 2.06 ± 1.53 | 1.05 ± 1.09 |
| *Chelon labrosus* | Mugilidae | MJ | 0.23 ± 0.09 | 0.14 ± 0.25 |
| *Ciliata mustela* | Gadidae | MJ | 1.45 ± 2.05 | 0.54 ± 0.42 |
| *Conger conger* | Congridae | MA | 0.25 ± 0.12 | 0.11 ± 0.13 |
| *Dicentrarchus labrax* | Moronidae | NU | 106.42 ± 104.87 | 28.44 ± 5.44 |
| *Dicologlossa hexophthalma* | Soleidae | MJ | 0 | 0.03 ± 0.04 |
| *Diplodus vulgaris* | Sparidae | MJ | 21.64 ± 21.09 | 3.75 ± 1.69 |
| *Echiichthys vipera* | Trachinidae | MA | 0.31 ± 0.44 | 0.09 ± 0.15 |
| *Engraulis encrasicolus* | Engraulidae | MA | 0.04 ± 0.06 | 0.57 ± 0.42 |
| *Gaidropsarus mediterraneus* | Gadidae | MA | 0 | 0.03 ± 0.05 |
| *Gambusia holbrooki* | Poeciliidae | FW | 0.18 ± 0.26 | 0 |
| *Gobius niger* | Gobiidae | ER | 2.28 ± 0.37 | 1.06 ± 0.24 |
| *Liza aurata* | Mugilidae | MJ | 0.11 ± 0.16 | 0.08 ± 0.08 |
| *Liza ramada* | Mugilidae | CA | 2.28 ± 2.51 | 1.40 ± 1.21 |
| *Mugil cephalus* | Mugilidae | MJ | 0.04 ± 0.05 | 0.03 ± 0.05 |
| *Mullus surmuletus* | Mullidae | MJ | 0.59 ± 0.06 | 0.86 ± 0.84 |
| *Nerophis lumbriciformis* | Syngnathidae | ER | 0 | 0.09 ± 0.16 |
| *Parablennius gattorugine* | Blennidae | MA | 0.05 ± 0.07 | 0 |
| *Platichthys flesus* | Pleuronactidae | NU | 17.77 ± 16.88 | 10.87 ± 4.24 |
| *Pomatoschistus microps* | Gobiidae | ER | 96.09 ± 14.07 | 45.22 ± 27.41 |
| *Pomatoschistus minutus* | Gobiidae | ER | 52.89 ± 54.79 | 11.71 ± 7.65 |
| *Sardina pilchardus* | Clupeidae | MJ | 1.61 ± 2.28 | 1.94 ± 3.25 |
| *Scophthalmus rhombus* | Scophthalmidae | MJ | 0.77 ± 0.74 | 0.12 ± 0.10 |
| *Solea lascaris* | Soleidae | MA | 0 | 0.28 ± 0.41 |
| *Solea senegalensis* | Soleidae | MJ | 0.99 ± 0.12 | 0.87 ± 0.65 |
| *Solea solea* | Soleidae | NU | 24.17 ± 6.59 | 14.05 ± 4.24 |
| *Sparus aurata* | Sparidae | MJ | 0.24 ± 0.21 | 0.11 ± 0.13 |
| *Spondyliosoma cantharus* | Sparidae | MA | 0.25 ± 0.11 | 0.24 ± 0.18 |
| *Symphodus bailloni* | Labridae | MA | 0.24 ± 0.34 | 0.60 ± 0.31 |
| *Syngnathus abaster* | Syngnathidae | ER | 1.91 ± 0.58 | 0.94 ± 0.83 |
| *Syngnathus acus* | Syngnathidae | ER | 2.72 ± 2.69 | 1.40 ± 1.23 |
| *Trisopterus luscus* | Gadidae | MA | 0.05 ± 0.07 | 1.25 ± 1.21 |

In the regular period, the most abundant species were *Dicentrarchus labrax*, *Solea solea*, *Platichthys flesus* (species that use the estuary as a nursery ground), *Pomatoschistus microps*, *Pomatoschistus minutus* (estuarine resident species) and *Diplodus vulgaris* (marine juvenile migrant species). The most abundant species in the dry period were the estuarine residents *P. microps*, *P. minutus* and *Atherina boyeri* and the nursery species *D. labrax*, *S. solea* and *P. flesus*. (Table IV)

Table IV. Species abundance ranking based on density values for regular years and dry years.

| **Regular Years** | | **Dry Years** | |
|---|---|---|---|
| *D. labrax* | 1 | *P. microps* | 1 |
| *P. microps* | 2 | *D. labrax* | 2 |
| *P. minutus* | 3 | *S. solea* | 3 |
| *S. solea* | 4 | *P. minutus* | 4 |
| *D. vulgaris* | 5 | *P. flesus* | 5 |
| *P. flesus* | 6 | *A. boyeri* | 6 |
| *A. anguilla* | 7 | *D. vulgaris* | 7 |
| *A. boyeri* | 8 | *A. anguilla* | 8 |
| *S. acus* | 9 | *S. pilchardus* | 9 |
| *G. niger* | 10 | *C. lyra* | 10 |
| *L. ramada* | 11 | *L. ramada* | 11 |
| *C. lucernus* | 12 | *S. acus* | 12 |
| *S. abaster* | 13 | *T. luscus* | 13 |
| *S. pilchardus* | 14 | *G. niger* | 14 |
| *C. mustela* | 15 | *C. lucernus* | 15 |
| *S. senegalensis* | 16 | *A. tobianus* | 16 |
| *A. minuta* | 17 | *A. presbyter* | 17 |
| *S. rhombus* | 18 | *S. abaster* | 18 |
| *M. surmuletus* | 19 | *S. senegalensis* | 19 |
| *C. lyra* | 20 | *M. surmuletus* | 20 |

According to the species ranking, the eight most abundant species from both periods were: *Anguilla anguilla*, *A. boyeri*, *D. labrax*, *D. vulgaris, P. microps*, *P. minutus*, *S. solea* and *P. flesus*. In the dry period, the marine adventitious species increased in the ranking and the marine juvenile migrant species decreased. In both dry and regular periods, the species that use the estuary as a nursery ground were present in the first places of the ranking. Freshwater species, such as *Barbus bocagei*, *Carassius auratus* and *Gambusia holbrooki*, were only found in the estuary during the regular years.

In the dry years, new marine species appeared in the estuary, which were not found in the estuary in the regular years. The new marine species were: *Arnoglossus laterna*, *Buglossidium luteum*, *Dicologlossa hexophthalma*, *Gaidropsarus mediterraneus,* and *Solea lascaris*. The estuarine resident *Nerophis lumbriciformis* was only found in the dry years, as well.

### 3.3. Distribution and abundance patterns

The total densities of the nursery species were higher in the regular years, when compared to the dry years. Although this ecological guild occurred in high densities in all the sampling stations, at S1 and in the dry years densities were much lower. In fact, in the dry years higher densities occurred at S2.

The marine adventitious species increased in density during the dry years, particularly at stations M and S1 (Figure. 3 and 4). These stations are located near the estuary mouth, which have higher salinity values. The marine adventitious species appeared for the first time at N2, during the dry years.

The densities of the estuarine resident species in the dry years were higher at N2 and S2 and in the regular years at M, S1 and N1. The density of the catadromous species was highest in the regular years. In the dry years the stations where the density was higher were S2 and N2. The freshwater adventitious species only appeared in the regular years at S2 and N2 stations, disappearing in the dry years.

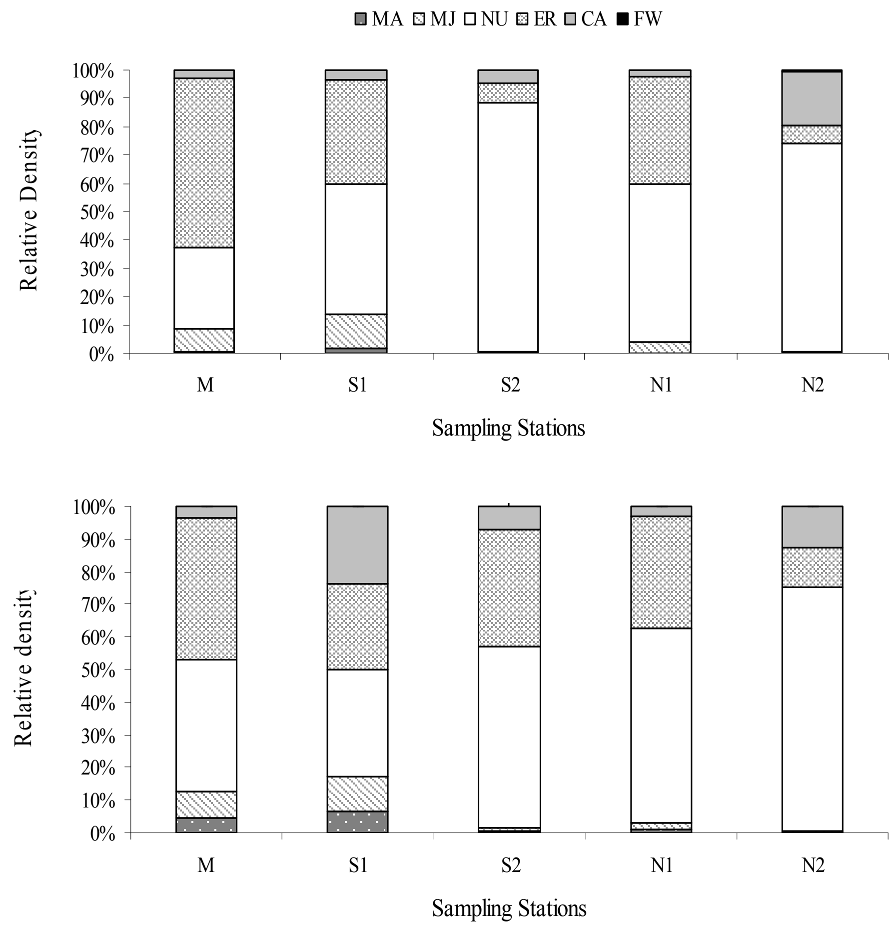


Figure 3. Relative density, per sampling station, according to the ecological guilds for regular years (A) and for dry years (B) (MA – marine adventitious species, MJ – marine juvenile migrant species, NU – species that use the estuary as a nursery ground, ER – estuarine resident species, CA – catadromous species and FW – freshwater adventitious species).

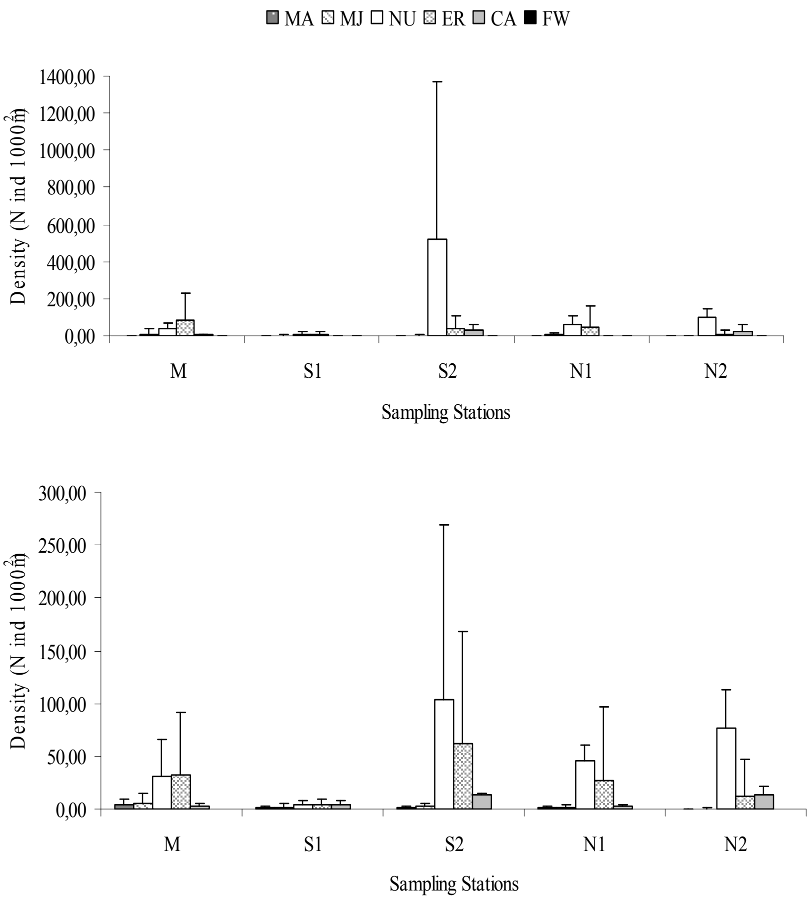


Figure 4. Variation of fish density, per sampling station, according to the ecological guild for regular years (A) and dry years (B) (standard deviation presented with lines on top of bars). (MA – marine adventitious species, MJ – marine juvenile migrant species, NU – species that use the estuary as a nursery ground, ER – estuarine resident species, CA – catadromous species and FW – freshwater adventitious species).

The 20 most abundant species from the regular and dry years represent 99% and 98% of the total fish population, respectively. According the forwards selection model applied previously to the db-RDA, only precipitation and salinity were considered significant, and therefore included in the analysis. According to the db-RDA (Figure 5) the total percentage of variation explained by the fish presence/absence data and their relationship with environmental variables was 68,9%.

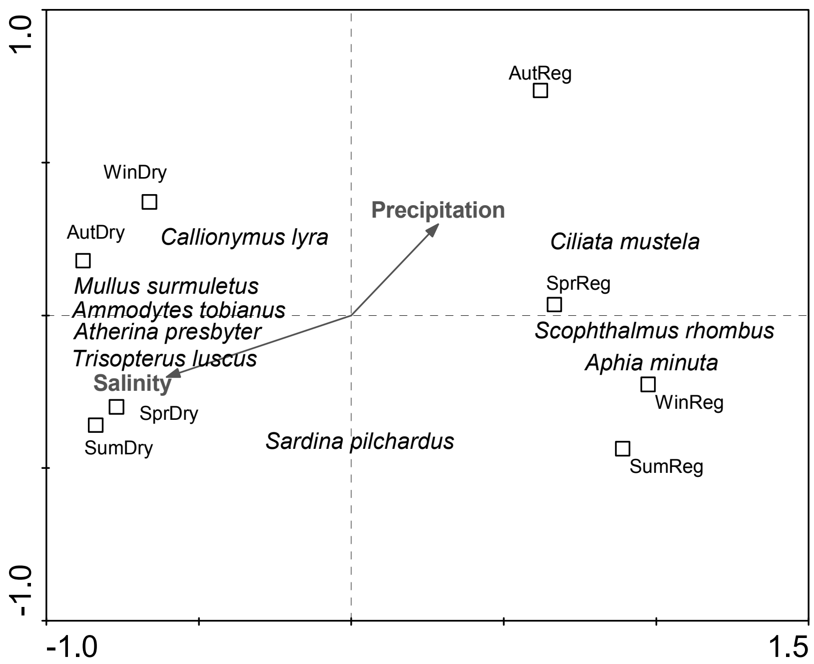


Figure 5. Distance-based redundancy analysis graph performed with the 20 most abundant species for both periods. (Sum – summer; Aut – autumn; Win – winter; Spr – spring; Reg – regular years; Dry – dry years)

In the db-RDA, a clear separation between regular and dry years could be observed. The dry years were associated with a more saline environment, while the regular years were associated with higher precipitation. The species associated to the dry years were *Callionymus lyra*, *Mullus surmuletus*, *Ammodytes tobianus*, *Atherina presbyter* and *Trisopterus luscus* and the ones associated with the regular years were *Ciliata mustela, Scophthalmus rhombus* and *Aphia minuta*. *Sardina pilchardus* was not specifically associated with the regular or the dry years like the previous species, as it appeared similarly in both years.

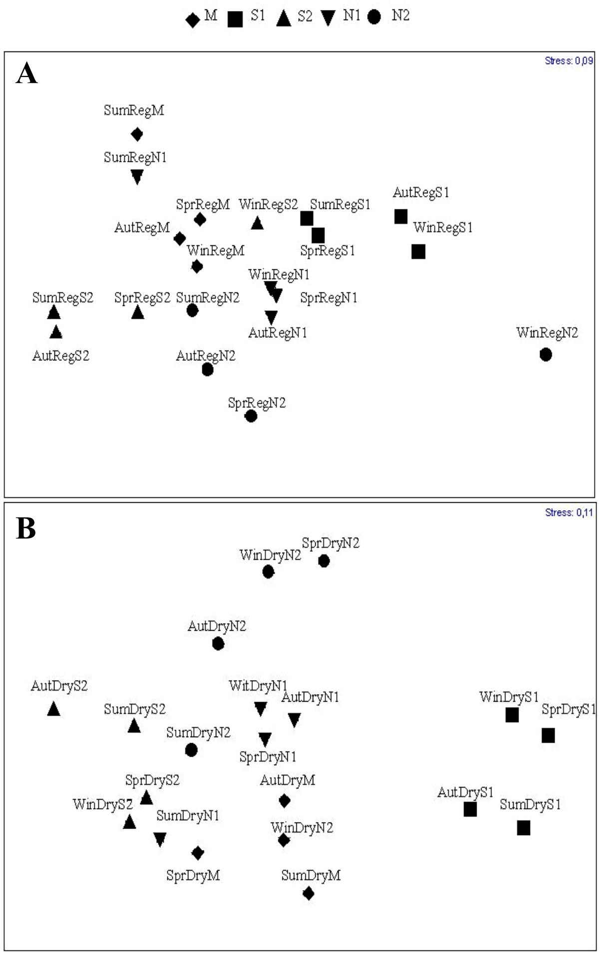


Figure 6. Two dimensional MDS ordination plot of the fish community for each season, per station in the regular years (A) and in the dry years (B). (Sum – summer; Aut – autumn; Win – winter; Spr – spring; Reg – regular years; Dry – dry years)

The MDS was performed separately for dry and regular periods, based on the total density of species for each season, with the total number of species (Figure 6). The ANOSIM test for differences among sampling stations proved significant differences for the dry period (R = 0.756, P = 0.001) and regular years (R=0.565, P= 0.001). The Pairwise tests grouped S1 and N2 (similar sampling stations) for the regular years, and grouped N1 and N2 for the dry years.

According to the SIMPER procedure (Table V) the average similarity within M station in the regular years was 51% and 53% for the dry years. The species that contributed for the similarity at M were *Syngnathus acus*, *Syngnathus abaster*, *S. solea*, *D. vulgaris* and *D. labrax*. All species were similar in the dry years, with the exception of *D. vulgaris* (which appeared only during the dry years), *C. lyra*, *T. luscus* and *Chelidonichthys lucernus* (which appeared only during the dry years). For S1 the average similarity was 45% for the regular years, and 50% for the dry years. The species that more contributed for the similarity in this station, during the regular years, were *S. solea*, *S. acus* and *P. microps*. With the exception of *S. acus*, all species did not contribute for the similarity in the dry years. Besides *S. acus* the other species that contributed for the similarity in the dry years were *D. labrax*, *Symphodus bailloni*, *C. mustela*, *S. abaster* and *D. vulgaris*. The average similarities at S2 during the regular and dry years were 38% and 52%, respectively. The species that contributed for the similarity during the regular years were *S. solea* and *S. acus*. In addiction to these two species, *A. boyeri* and *P. flesus* were also found during the dry years. The average similarity at N1 was 44% for the regular years and 52% for the dry years. The species that contributed for the similarity in both periods were the same with the exception of *C. lucernus*, which only appear in the dry years; the species were *D. labrax*, *S. acus*, *S. solea* and *P. flesus*. The average similarities for regular and dry years at N2 were 28% and 40%, respectively.

The species that contributed for the similarity for both periods were the same: *S. solea*, *P. flesus* and *D. labrax*.

Table V. Similarities (%) in the species composition of each sampling station per regular and dry periods, with indication of the mean abundance and contribution of the species (and ecological guild) for the similarity between each sampling station, determined by the SIMPER analysis. (MA – marine adventitious species, MJ – marine juvenile migrant species, NU – species that use the estuary as a nursery ground, ER – estuarine resident species, CA – catadromous species and FW – freshwater adventitious species)

| | | **M** | | **S1** | | **S2** | | **N1** | | **N2** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SIMPER Species** | **Ecological Guild** | Regular | Dry | Regular | Dry | Regular | Dry | Regular | Dry | Regular | Dry |
| | | 51% | 53% | 45% | 50 % | 38% | 52% | 44% | 52% | 28% | 40% |
| *A. boyeri* | ER | | | | | | 14 (14%) | | | | |
| *C. lucernus* | MJ | | 1 (2%) | | | | | 6 (5%) | | | |
| *C. lyra* | MA | | 2 (6%) | | | | | | | | |
| *C. mustela* | MJ | | | | 1 (12%) | | | | | | |
| *D. labrax* | NU | 2 (2%) | 1 (2%) | | 1 (14%) | | | 14 (33%) | 5 (24%) | 5 (7%) | 3 (9%) |
| *D. vulgaris* | MJ | 11 (10%) | | | 1 (8%) | | | | | | |
| *P. flesus* | NU | | | | | | 2 (2%) | 4 (14%) | 3 (7%) | 15 (39%) | 9 (44%) |
| *P. microps* | ER | | | 3 (26%) | | | | | | | |
| *S. abaster* | ER | 30 (22%) | 10 (27%) | | 1 (9%) | | | | | | |
| *S. acus* | ER | 47 (47%) | 12 (26%) | 4 (27%) | 2 (35%) | 24 (22%) | 26 (42%) | 43 (23%) | 17 (38%) | | |
| *S. bailloni* | MA | | | | 1 (14%) | | | | | | |
| *S. solea* | NU | 9 (12%) | 7 (24%) | 4 (37%) | | 187 (68%) | 30 (32%) | 6 (19%) | 5 (23%) | 17 (44%) | 10 (39%) |
| *T. luscus* | MA | | 1 (3%) | | | | | | | | |

Chapter 4

# Discussion

In 2005 an extreme drought event took place in Portugal and since then other drought periods were reported. The decrease in precipitation and freshwater stored in dams led to a decrease in runoff. The variations in river flow altered the water salinity, due to the decrease of freshwater flow and also to the intrusion of seawater into the estuary. According to Martinho et al (2007a), in the Mondego estuary strong positive salinity anomalies were observed mainly in 2005, with higher values than the mean salinity occurring all over the estuary. The variations in river flow in estuaries influence not only the salinity, but also the biochemical properties of the water body (Whitfield, 1999b).

In the present study, the regular period was clearly separated from the dry period, with the distinction between periods correlated with salinity and precipitation. The dry years were correlated with a more saline environment, while the regular years were correlated with higher precipitation and lower salinity. This climatic variability in the Mondego estuary led to a modification in the fish community composition. In the dry years, new marine species appeared, such as *A. laterna*, *B. luteum*, *D. hexophtalma*, *G. mediterraneus* and *S. lascaris*, which had never been found before in the estuary. The marine adventitious species such as *C. lyra*, *A. tobianus* and *T. luscus*, the marine juvenile migrant *M. surmuletus*, and the estuarine resident *A. presbyter* also appeared more often or with higher densities in the dry period. On the regular period, a lower diversity of marine species occurred, yet higher densities for the overall fish community were observed, especially for the marine juvenile using the estuary as nursery *D. labrax, P. flesus* and *S. solea*, for the estuarine residents *P. microps* and *P. minutus*, and some marine juvenile migrant species, such *C. mustela*, *S. rhombus* and *A. minuta*. Also, and on the opposite to the dry period, freshwater species such as *B. bocagei*, *C. auratus*, *G. holbrooki* appeared in the estuary only in the regular years. Due to the global increase in the Mondego estuary salinity, these species tended to disappear. According to

Leitão et al. (2007), in previous surveys in 1988-1992 ten freshwater species were found in the estuary, but in the present study only three species were found in the regular years, and none in the dry years. Freshwater species were found mainly at the most upstream areas of the estuary (S2 and N2), in areas where salinity values were lower and freshwater flow was higher. Although the fish community changed in the two periods, the eight more abundant species remained the same, though with different densities. This can indicate stability within the Mondego estuary, in parallel to observations in other estuaries (e.g. James et al., 2008).

At the mouth of the estuary, it was observed a decrease in the abundance of the estuarine resident species in the dry years, when compared to the regular years. This decrease was mainly due to *P. minutus*, since *P. microps* supports a wide range of salinity and temperature (Leitão et al., 2006; Dolbeth et al., 2007b). Since the salinity in this area did not differ between dry and regular years, the decrease of this guild could be attributed to some extent to an increase in predation (Dolbeth et al., 2007b), as in this area the number of marine adventitious increased in the dry years, leading to a weakening in the recruitment. According to Dolbeth (2007b), this decrease can also be due to high mortality or migration to the sea, behavioural differences and inter-annual variability in the recruitment's success. In fact, Drake et al. (2002) suggested that short-term salinity variations might affect negatively species that complete their lifecycle inside the estuary, which is the case of the estuarine residents.

In the Mondego estuary, the catadromous species density decreased in the dry years, especially at the most upstream areas (N2), where they were more abundant in the regular years. Catadromous and freshwater species live in waters with high freshwater inputs (Leitão et al., 2007) and in agreement, and due to the decrease in the dry years, salinity seemed to have an influence on the distribution of the catadromous species, since salinity values were higher during the extreme drought. Almeida et al. (2002) also pointed out that river flow is an important factor for other anadromous migratory species, such as the sea lamprey (*Petromyzon marinus*).

The abundance of the nursery species decreased in the upstream areas of the south arm (S2), during the dry period. In the regular years, at S2, the nursery species abundance represented almost 90% of the total community, but in the dry years this ecological guild represented only 60%. For *P. flesus* and *S. solea*, the nursery grounds are normally located at the upstream areas with lower salinity (Cabral et al., 2007). In the dry years, salinity increased in the upstream areas, which led to a global decrease in the nursery species abundance. The decrease of the nursery species could also be due to a reduction in the chemical cues due to low river flow; chemical cues can influence the orientation of larvae towards the estuary (Vinagre et al., 2007), and as a consequence, low runoff and the consequent increase in salinity could affect the recruitment of nursery species (Dolbeth et al., 2008a). High salinity values and the higher water temperatures felt in 2005 could also have influenced the larvae and juvenile development of *D. labrax* and *P. flesus* (Dolbeth et al., 2008a).

The structure of the fish community of the Mondego estuary during the regular years was characterized by marine species in the downstream areas (M and S1), in the upstream areas (N2) were found more freshwater and catadromous species, and in the middle areas (S2 and N1) were found more nursery and estuarine resident species. The same structure was also found in the dry years, with the exception of the disappearance of the freshwater species, and a higher incursion of the marine species in the middle areas. This type of community structure, responding to the estuarine salinity gradient, has been found elsewhere: e.g. in Rio de La Plata estuary (Argentina and Uruguay) (Jaureguizar et al., 2003), in the Gambia River estuary (Gambia) (Simier et al., 2006), and Tagus (Portugal) and Elbe (Germany) (Thiel et al., 2003), where most of the marine species were found in the outer area, the freshwater species in the inner area and estuarine resident species in the middle area. An increase in marine species was observed at the downstream areas, during the dry years, since saline incursion created a suitable environment for these species. At the upstream areas, there were no changes regarding the species composition, which were mainly nursery species.

In the Tagus estuary (Portugal), no differences in species richness or in guild structure were found between wet and dry years (Costa et al., 2007). However, in the Mondego estuary, differences were found between both periods. In the dry years, more species were found (38 species, 23 families) than the regular years (36 species, 20 families) and the guild structure was also different: 6 guilds were found during the regular years, while only five were found during the dry years, since no freshwater species were found. In the Tagus estuary, higher densities were found in the dry years (Costa et al., 2007), while in the Mondego estuary the higher density values were found during the regular years. Similar results were found in Bridgwater bay (England) (Henderson, 2007).

In conclusion, the regular years were associated with higher precipitation and runoff values, while the dry years were associated with high salinity values in all sampling stations. During the dry years, new marine species appeared in the Mondego estuary, due to an increase in salinity. On the contrary, the freshwater species had been decreasing their density, and were absent in the estuary during the dry period. As a final remark, it should be stated that changes reported in the structure and composition of this estuarine fish community should be taken in account in future management plans, since extreme fluctuations in precipitation regimes have been predicted to increase in a near future. Also, changes in recruitment patterns and predator-prey interactions might occur, due to changes in habitat (ex: salinity ranges, freshwater inputs), with strong implications for the estuarine environment.

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