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The use of nursery areas by juvenile fish in a temperate estuary, Portugal

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Abstract The nursery role of the Mondego estuary for marine fish species was studied between June 2003 and May 2004. The spatial and temporal distribution and abundance patterns of 0-group *Dicentrarchus labrax* (Linnaeus, 1758), *Platichthys flesus* (Linnaeus, 1758) and *Solea solea* (Linnaeus, 1758) were analyzed based on monthly sampling surveys in five stations along the estuarine gradient. Fishing took place during the night at low water of spring tides, using a 2 m beam trawl. The spatial patterns of estuarine colonization were different according to species. *D. labrax* showed a wider distribution, but the main nursery ground was the same as for *S. solea*. Highest densities of *S. solea* juveniles were found in oligohaline areas, with muddy bottoms and high benthic invertebrates availability, while *P. flesus* occurred mainly in the sandy uppermost areas. *D. labrax* was found in both these areas. Fish abundance in the estuary mainly reflected seasonal changes.

Keywords Mondego river · Estuarine fish · Nursery areas · Habitat use · Eutrophication

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Towards an integrated knowledge and management of estuarine systems

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Introduction

Estuaries have long been recognized as important nursery habitats for several fish species (Haedrich, 1983; Beck et al., 2001). These coastal systems usually present high food availability and low predation pressure, and are therefore used by fish species during their first years of life (Haedrich, 1983).

Presently, one of the main problems for fish in estuaries is habitat loss, which combined with the increasing eutrophication processes in most of the World's estuarine systems, is contributing to a decrease in their abundance. Increasing pressure from human development urges the need for identification and preservation of habitats critical for survival and sustainable utilization of estuarine and marine species (Stoner et al., 2001). Such measures were taken into account in the US Magnuson-Stevens Fishery Conservation and Management Act, as well as in other milestone documents produced by the European Union, such as the Water Framework Directive or the European Strategy for the Marine Ecosystems.

Among the most common fishes along the North Atlantic coasts that use estuaries and bays as nursery areas are sea bass, *Dicentrarchus labrax* (Linnaeus, 1758), flounder, *Platichthys flesus* (Linnaeus, 1758) and sole, *Solea solea* (Linnaeus, 1758). Throughout the Portuguese estuaries, several studies were carried out in order to evaluate the abundance patterns of these species, as well as the nursery role of these Portuguese coastal waters (e.g., Costa et al., 2002b, for the Mira estuary; Jorge et al., 2002, for the Modego estuary; Cabral & Costa, 1999, 2001; Cabral, 2003, for the Tagus estuary; Cabral, 2000, for the Sado estuary; Vasconcelos, 2001, for the Douro estuary; Gordo, 1989, for the Ria de Aveiro).

The young-of-the-year of these fish species enter in estuaries and concentrate in nursery grounds in late spring, where they remain until the end of autumn, dispersing afterwards to deeper areas (Kelley, 1988; Dorel et al., 1991). Competition between these species may take place, although it seems to be rare and prevented by abundant food resources, or even by resource partitioning produced by the likely competitors (Amara et al., 2001; Costa et al., 2002a), namely spatial and temporal segregation within the nursery areas.

The Mondego estuary, Portugal, provides a good environmental system to assess two of the most common problems affecting estuaries: (a) the increase of organic pollution that usually leads to a shift in primary producers (in the south branch) and (b) dredging activities (in the north branch) related to harbour facilities and to economical growth at the regional scale. As in many other estuaries, the south branch of the Mondego has undergone significant eutrophication due to organic enrichment (Pardal et al., 2000, 2004; Marques et al., 2003; Cardoso et al., 2004). In intertidal areas, despite interannual variations over the last 20 years, a consistent decrease in species diversity and secondary production from the less stressed areas to the ones exhibiting stronger symptoms of eutrophication have been noticed (Dolbeth et al., 2003; Cardoso et al., 2004; Pardal et al., 2004; Salas et al., 2004). Since 1998, some management measures were implemented, which resulted in a decrease of the nutrient loading to the system and an increase in water transparency and velocities leading, at the present time, to the slow recovery of the ecological quality of the estuary. The present paper evaluates the nursery role of the Mondego estuary for the commercial fish species *D. labrax*, *P. flesus* and *S. solea* during this ecological recovery phase, and studies the temporal and spatial patterns of abundance of juvenile fish within the estuary.

Materials and methods

Study area

The Mondego River estuary (40°08′ N, 8°50′ W) (Fig. 1), a small estuary in the western coast of Portugal, is divided in two branches in its terminal part, limited by an alluvium formed island—Murraceira island, that join again near the mouth. These two branches, north and south, have different hydrologic caracteristics. The north branch is deeper (5–10 m during high tide, tidal range about 2–3 m), while the south branch (2–4 m deep, during high tide) is almost silted up in the upstream areas, which causes the freshwater of the river to flow essentially through the north branch. The inflow of freshwater to the south branch, although relatively small, is mainly carried out by a tributary system, the Pranto River, which is controlled by a sluice and is regulated according to the water needs in the rice fields from the Mondego agricultural valley. The intertidal areas represent up to 75% of the whole estuary, depending on the tidal range.

Sampling procedures and laboratory work

The spatial and temporal patterns of abundance of 0-group *D. labrax*, *P. flesus* and *S. solea* in the Mondego estuary were analysed based on monthly sampling surveys in five stations (A, B, C, D and E) (Fig. 1) along the estuarine gradient. Juvenile fishes were particularly targeted. Fishing took place from June 2003–May 2004, during the night, at low water of spring tides (due to the high water transparency and to a better gear efficiency), using a 2 m beam trawl with a tickler chain and 5 mm mesh-size in the cod end. Three trawls were towed

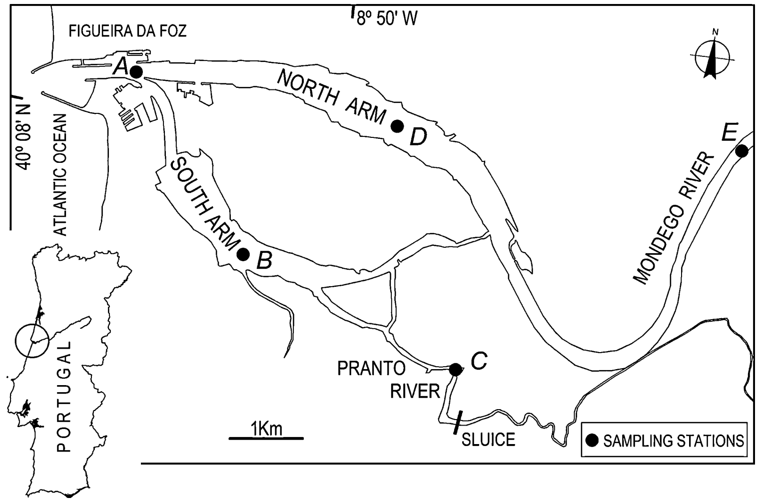

Fig. 1 The Mondego estuary: location of the five sampling stations (**A**–**E**)

for an average duration of 5 min each, at all sampling stations, covering at least an area of 500 m^2. Temperature, salinity, dissolved oxygen, pH and depth were measured when fishing took place. All fish caught were identified, counted, measured and weighed. The sediment of the sampling areas was characterized based on samples collected in the summer and autumn of 2003, and in the winter and spring of 2004, using a van Veen grab. Dried sediment samples were incinerated at 450°C, sorted in a sieve series and weighed according to grain size to calculate the granulometry. Benthic invertebrate's biomass (AFDW) was determined from samples collected simultaneously to the previous for granulometric purposes, after incineration at 450°C.

Data analysis

Fish density data (number of individuals per 1,000 m^2) was inserted into ArcGis software (version 8.3) as the average values for summer, autumn, winter and spring. A canonical correspondence analysis (CCA) was used in order to evaluate relationships between *D. labrax*, *P. flesus* and *S. solea* juveniles' densities and environmental factors, using CANOCO software (version 4.0). Temperature, salinity, dissolved oxygen, type of sediment, algae biomass, mean depth and benthos biomass were also included in the analysis as an environmental data matrix. In both analyses, 2 age-groups were accounted for: 0-group, formed by individuals with no more than 12 cm for sea bass, 15 cm for flounder and 17 cm for sole; 1-group or older, formed by all larger individuals. This stratification was based on size frequency distributions (Martinho, unpublished results).

Results

Environmental conditions in the sampling areas

Temperature and salinity showed the lowest values in the winter and the highest in the summer (Fig. 2), exhibiting a typical pattern for a temperate region. Most of the environmental variables measured at the sampling sites (Table 1) presented a longitudinal gradient, from the upper areas to the mouth of the estuary. Stations A, B and C presented the highest salinity values, while in station E salinities were low. Temperature was higher in the uppermost sampling areas, which were also the shallower ones. Dissolved oxygen showed a similar pattern with both temperature and depth. Although Secchi depth was not measured (as the surveys took place at night), high turbidity was found at station C. The sediment of the most upstream areas was mostly composed of medium and coarse sand, contrasting to the downstream ones that consisted mainly in medium to fine sand, with larger amounts of mud at station C.

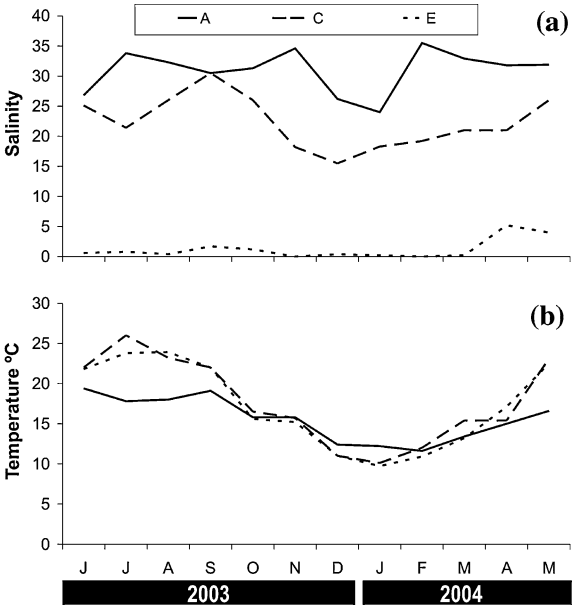

Fig. 2 Monthly variation of bottom (**a**) salinity and (**b**) temperature in sampling stations A, C and E, from June 2003–May 2004

Spatial and abundance patterns of seabass, flounder and sole juveniles

To overcome the main difficulty when modelling the highly dynamic estuarine systems, average density values for each season of the year were calculated for sea bass, flounder and sole, and were then mapped (Figs. 3–5). The highest densities of *D. labrax* were found in station C, the Pranto River, with an average of 191 ind. 1,000 m^{-2} in the summer, and a peak value of 320 ind. 1,000 m^{-2}, which was registered in November (Fig. 3). In the winter months, movements of juveniles towards downstream areas of the estuary were observed, with most of the 0-group sea bass being found at stations A and D. In the spring, a recolonization pattern to the nursery areas was registered. 0-group sea bass were already present in the estuary when the sampling program began, and remained there throughout the year. Nevertheless, until the end of the present study, no 0-group bass from the year-class of 2004 was found in the estuary.

Flounder had a distinct spatial distribution in the Mondego (Fig. 3), as the majority of the juveniles were only found in the northern branch of the estuary, namely in the uppermost areas, with highest average densities being recorded in the summer (15 ind. 1,000 m^{-2}) (Fig. 4), and autumn. The maximum density was recorded in June 2003 (30 ind. 1,000 m^{-2}), at station E. The movement towards the downstream areas in the winter was also registered for flounder. In the spring, a recolonization pattern was observed, but low densities of the young-of-the-year were estimated. First recruits of 2004 were found in April.

Sole showed a similar distribution between both the north and the south branches (Fig. 5) during summer and autumn, although the highest average and total density values were found in the Pranto River (10 ind. 1,000 m^{-2} and 23 ind. 1,000 m^{-2}, respectively). A movement towards the mouth of the estuary was recorded in the winter (Fig. 4). The young-of-the-year of 2004 started to colonize the estuary in the end of January 2004, remaining only in the north branch.

Table 1 Mean values of environmental variables measured in the sampling stations considered in the Mondego estuary (standard deviation between brackets)

Sampling station	A	B	C	D	E
Salinity (ppm)	30.3 (3.4)	28.3 (4.3)	22.7 (4.4)	20.1 (6.6)	1.2 (1.7)
Temperature (°C)	15.6 (2.7)	17.2 (3.1)	18.0 (5.3)	16.8 (3.6)	17.2 (5.4)
O_2 (%)	102.1 (7.8)	95.9 (6.1)	85.3 (8.4)	93.3 (7.2)	85.1 (14.6)
pH	8.2 (0.1)	8.1 (0.2)	7.8 (0.2)	8.1 (0.1)	7.9 (0.4)
% Mud in the sediment	2.3 (3.4)	0.7 (0.7)	2.1 (1.4)	0.0 (0.0)	0.1 (0.1)
% Silt in the sediment	7.7 (11.4)	2.2 (2.1)	9.2 (7.8)	0.0 (0.0)	0.2 (0.1)
% Fine sand in the sediment	43.6 (13.1)	36.3 (10.0)	38.8 (1.1)	2.0 (1.6)	1.3 (0.2)
% Medium sand in the sediment	28.6 (13.3)	30.0 (10.1)	24.6 (11.5)	51.7 (34.7)	22.6 (1.9)
% Coarse sand in the sediment	16.5 (21.4)	30.5 (19.1)	24.1 (12.5)	45.9 (36.5)	75.5 (1.5)
Depth (high tide) (m)	8.7 (1.2)	2.3 (0.4)	2.4 (1.0)	5.5 (0.5)	4.5 (0.3)
Benthos biomass (g m^{-2})	3,6 (5.3)	0.4 (0.2)	1.2 (1.2)	0.0 (0.0)	3.8 (4.6)
Algae biomass (g m^{-2})	0.5 (0.5)	0.9 (2.3)	2.9 (3.6)	0.0 (0.0)	0.0 (0.0)

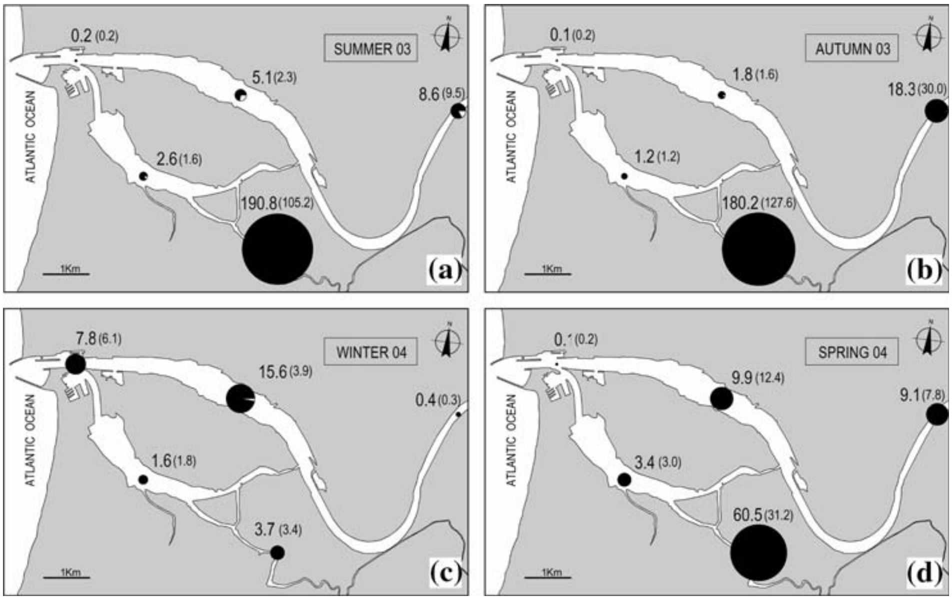

Fig. 3 *D. labrax* juveniles mean densities (standard deviation between brackets) within the Mondego estuary, per season: (**a**) Summer 2003, (**b**) Autumn 2003, (**c**) Winter 2004 and (**d**) Spring 2004. (●, 0-group fish; ○, 1-group or older fish. Circles are proportional to density values

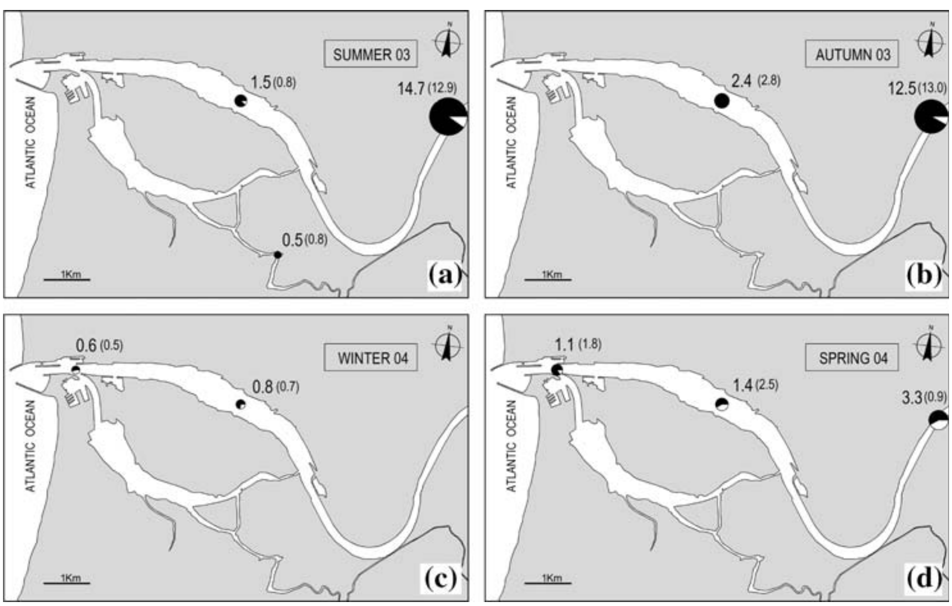

Fig. 4 *P. flesus* juveniles mean densities (standard deviation between brackets) within the Mondego estuary, per season: (**a**) Summer 2003, (**b**) Autumn 2003, (**c**) Winter 2004 and (**d**) Spring 2004. (●, 0-group fish; ○, 1-group or older fish. Circles are proportional to density values

Distribution patterns related to environmental factors

The first two axes of the CCA performed using densities data according to sampling areas and seasons accounted for 74% of the total variance and 83% of the variance due to fish abundance—environment relations (Fig. 6). Among the environmental variables considered, depth, percentage of coarse and fine sand, silt and mud

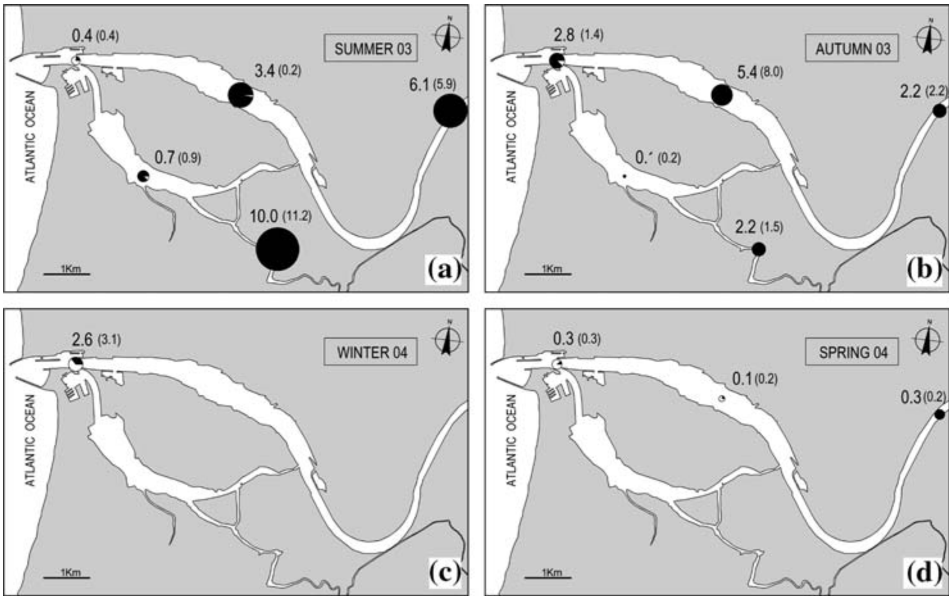

Fig. 5 *S. solea* juveniles mean densities (standard deviation between brackets) within the Mondego estuary, per season: (**a**) Summer 2003, (**b**) Autumn 2003, (**c**) Winter 2004 and (**d**) Spring 2004. (●, 0-group fish; ○, 1-group or older fish. Circles are proportional to density values

in de sediment, salinity and dissolved oxygen presented the highest magnitude, whereas medium sand and benthic invertebrates' biomass influenced the least the distribution of the three fish species within the estuary.

In the CCA diagram, segregation between 0-group and older age-groups of *D. labrax*, *P. flesus* and *S. solea* were observed (Fig. 6). The sea bass 0-group was mostly related to Station C throughout the year, while older bass were mainly related to stations D and E, which are deeper and with higher benthic invertebrate abundance. Flounder 0-group and older age-groups were mostly related to stations D and E at all times, except in the winter. Sole first year juveniles were positively correlated to medium sand and benthic invertebrates abundance, at stations D and E in summer and autumn months, while in the following years, deeper and more saline waters were preferred, mainly in the winter.

Discussion

The results obtained in the present study outlined that the seasonal changes in the environment were the main factor determining the abundance pattern of sea bass, flounder and sole in the Mondego estuary. For these three species the highest densities occurred in the summer and autumn, while the lowest values of 0-group fish abundance were, in opposition, registered in the winter. This decrease in abundance in this period is surely related to dispersion movements towards the mouth of the estuary, i.e., deeper and more saline waters. This seawards migration has been related to water temperature, which falls down rapidly by the end of autumn until the beginning of winter in the uppermost areas (Aprahamian & Barr, 1985), as observed in the Mondego estuary during the study period. However, Jennings et al. (1991) suggested that the timing of this migration by 0-group sea bass is determined by the temperature differential between nursery habitats and the open sea, rather than an absolute temperature value. The estimated abundance peaks during the summer reflected mostly the period of estuarine colonization by 0-group fish: in southern Europe coastal areas *D. labrax* spawns from January to March (Arias, 1980), *P. flesus* spawns from December to February (Cunha, 1983), while *S. solea* spawns mainly in the winter (Koutsikopoulos & Lacroix, 1992), from January to April (Dinis, 1986).

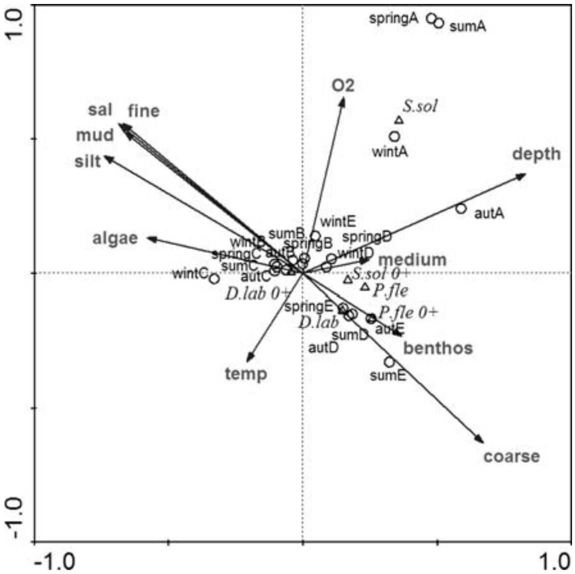

Fig. 6 Ordination diagram for the first two axes of the canonical correspondence analysis performed using fish density data (*D.lab 0+*—*D. labrax* 0-group; *D.lab*—*D. labrax* older fish; *P.fle 0+*—*P. flesus* 0-group; *P.fle*—*P. flesus* older fish; *S.sol 0+*—*S. solea* 0-group; *S.sol*—*S. solea* older fish; temp—temperature; sal—salinity; algae—algae biomass; mud—% of mud; silt—% of silt; medium—% of medium sand; coarse—% of coarse sand; fine—% of fine sand; O_2—dissolved oxygen; benthos—benthic invertebrates biomass; sum—summer; aut—autumn; wint—winter; spring—spring; A—sampling station A; B—sampling station B; C—sampling station C; D—sampling station D; E—sampling station E)

Sea bass juveniles clearly occurred in the Pranto River nursery area throughout the year. These were the most turbid waters found in the estuary which, according to Costa et al. (2002a), are considered beneficial to juveniles by reducing predation pressure and favoring the development of suitable food associated with shallow waters and soft and fine sediment grounds. The reason for the absence of juveniles of the year-class of 2004 until May remains uncertain. Previous studies in the English (Claridge & Potter, 1983) and German coasts (Thiel et al., 1995) showed that good recruitments took place in years where warm sea temperatures were registered. Nevertheless, Cabral & Costa (2001) suggested that high interannual variations can occur, determined by either density dependent (within nurseries) (Rogers, 1994) and independent (related to oceanographic processes) (Rinsdorp et al., 1992) factors. A combination of fluvial regime (Le Pape et al., 2003) and tidal regime (Marchand, 1991) may also contribute to estuarine colonization success and account for a fraction of recruitment variability.

The presence of juveniles within the Modego nursery grounds in winter was contrary to what has been reported for the Tejo estuary (south to the Mondego), where 0-group sea bass leave in the first winter and return in the following spring (e.g., Cabral & Costa, 2001). However, the presence of young sea bass in the nursery grounds in the winter has also been reported for the Ria de Aveiro, Portugal (Gordo, 1989). Holden & Williams (1974) also reported that, in English coastal waters, sea bass stay permanently in estuaries for 2–3 years.

According to Dorel et al. (1991), during the first three years of life, young soles periodically migrate between the inshore, sheltered, productive but variable ecosystems and the offshore stable but less productive areas. The results obtained for *S. solea* are consistent with this pattern, as in the winter months juvenile soles were only found in the mouth of the estuary. The majority of fish caught belonged to 0- and 1-group, which indicates that soles stay in the Mondego estuary for a period of about 2 years, since no older individuals were caught. As observed in the northern Bay of Biscay, by Amara et al. (1993), who caught metamorphosing sole larvae in the beginning of February, spawning of *S. solea* occurred in the winter, as juveniles were first captured in late January.

Flounder presented a different abundance pattern. First juveniles were found in the spring, but in low numbers. This weak year-class strength could point to the effects of global warming in the rise of sea water temperature (among other hydrological processes), since it is known that flounder spawning success is drastically reduced in water above 12°C (von Westernhagen, 1970), or just the interannual fluctuations that can occur. Another factor that may be related with this low abundance was the increase in salinity in 2004 in station E, that could have led to a colonization of more upstream areas. Similar to the Mondego estuary, the preference for low salinity waters has been recorded in other estuaries, namely in the

Netherlands (Kerstan, 1991; van der Veer et al., 1991). Most of the individuals caught were 0-group and 1-group, which indicates that young flounders remain in the Mondego estuary for about 2 years.

The lowest densities of all species were found at station B (the south branch of the estuary), probably due to the low water level during ebb tides combined with a high water transparency, thus the fish becoming more exposed to predators and to higher temperatures. This has also been the area in the Mondego estuary that has suffered the highest impact of eutrophication, namely macroalgae blooms, which among other effects can cause reduced abundance of invertebrate prey for fishes and shorebirds (Raffaelli et al., 1998). Cloern (2001) also suggested that an impact of high biomass accumulations of macroalgae (due to nutrient enrichment) within coastal food webs can be a change in the selective forces that regulate the biological diversity at all trophic levels.

Spatial niche overlap between all species was observed, but competition is probably diminished by the abundant food supply, the ability to explore different microhabitats within the main nursery grounds, as well as by different timings (Macpherson, 1981; Amara et al., 2001).

The distribution within the estuary was mainly due to the estuarine gradient, as 0-group fish were mostly present in the uppermost areas of the estuary and, in opposition, older fish occupied deeper waters. Mainly in the summer and autumn, juveniles were associated with stations C, D and E. In the winter, a downwards movement was observed to deeper and more saline areas, closest to the sea. However, it is always difficult to state whether the distribution of one species is related to one particular environmental characteristic, rather than a combinaton of them (Gordo & Cabral, 2001), as fish distribution can be the result of a compromise between local conditions of the nursery grounds and both optimum and tolerance physiological levels.

From the ecological management point of view, the impact of anthropogenic activities in the estuary, namely eutrophication, could not be directly assessed using fish as indicators. Former studies in the Mondego estuary were conducted over 15 years ago, and its importance as a nursery ground was not fully explored. However, the decrease in fish species richness suggested that several changes in the habitat and in the environment took place due to these pressures. Nevertheless, knowledge of the decrease in species richness and secondary production at the intertidal level in the most affected areas, allied with the fact that marine juvenile fish that use estuaries as nursery areas are benthic feeders, suggests that the eutrophication processes that have taken place in the last decade caused severe impacts at higher trophic levels (e.g., Dolbeth et al., 2003).

On the other hand, the sampling program was conducted after a management plan took place so, despite interannual variations, probably higher food availability and more stable conditions throughout the estuary will lead to an increase in the abundance of fish species. The high densities recorded for these three species suggest that, despite its relative small size and area, the Mondego estuary provides an important nursery ground for these marine species, having a significant role in sustaining coastal fisheries stocks. However, this can only be confirmed by future studies aiming at these species, as well as to other juvenile marine migrants, in terms of drivers, pressures and relation with other suprabenthic invertebrate species. An application of this work could be related to the need of indicators of habitat status, as planned by the European Water Framework Directive for the transitional waters.

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