Estuarine colonization, population structure and nursery functioning for 0-group sea bass (Dicentrarchus labrax), flounder (Platichthys flesus) and sole (Solea solea) in a mesotidal temperate estuary

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Abstract:

The function of the Mondego estuary as a fish nursery habitat was investigated from June 2003 to June 2004 by comparing the timing of estuarine colonization with juveniles of sea bass Dicentrarchus labrax, flounder Platichthys flesus, and sole Solea solea, while also analysing their population structure, growth and diet composition. Differences in the onset of estuarine colonization were observed, since sole juveniles were the first to enter the estuary (in January), followed by flounder in April and sea bass in June. The estuarine population of these species consisted of several age-groups, although the majority of individuals belonged to age-groups 0 and 1. The growth rates determined for 0-group fish were within the range of those reported for other European estuarine systems. Some differences were also recognized regarding the timing of estuarine colonization and the length of the growing season. Diet of 0-group sea bass consisted mainly of Crustacea, Polychaeta and Mollusca. Flounder juveniles fed chiefly on Amphipoda (especially Corophium spp.), with Polychaeta, Isopoda and Decapoda also being common prey. The diet of 0-group sole was dominated by Polychaeta, with Amphipoda, Mollusca and Decapoda ranking highest, with other important benthic organisms also being present. Dietary overlap among these species was relatively low.

Keywords: Estuarine colonization, Nursery areas, Feeding ecology, Trophic niche overlap, Mondego estuary

Introduction
Estuaries are recognised to play an important role for a large number of marine fish species as nursery habitats and migration routes. According to Beck et al. (2001), the nursery role of estuarine areas implies high densities of fish during the first years, juveniles finding refuge from predators, high food availability and favourable conditions for rapid growth and good survival, thereby contributing significantly to the population recruitment. Recently, Dahlgren et al. (2006) proposed the concept of Effective Juvenile Habitat in order to describe fish habitats that are most important, regardless of area coverage, for their overall contribution to population size. Nevertheless, estuarine areas have long been subjected to anthropogenic pressures. Waste disposal from human activities and its consistent effects, particularly eutrophication, can have serious impacts on biological communities (Pardal et al., 2000; Dolbeth et al., 2003) changing the quantity and/or the quality of suitable habitats.

In estuaries, juveniles undertake upstream/downstream movements (Coggan and Dando, 1988; Dorel et al., 1991), which under particular circumstances may enhance their survival potential during winter months (Henderson and Seaby, 2005). Still, recruitment’s strength and pattern variations are acknowledged to be mainly determined by various processes operating during the early life (mainly larval and post-settlement stages): tidal transport, wind regime, fluvial discharge, and predation (Marchand, 1991; Leggett and DeBlois, 1994; Van der Veer et al., 2000). Accordingly, shifts in the estuarine environment and in predation pressure can lead to important fluctuations in recruitment and population dynamics (Phil, 1990; Nash and Geffen, 2000). During the estuarine phase, the use of resources by organisms has a major influence on population and community interactions, on the dynamics of resource availability, and on the fate of resources in the ecosystem.
As a result, resource partitioning within estuarine fish species is an important and interesting issue for understanding the structure and dynamics of these communities (Cabral, 2000).

Sea bass, *Dicentrarchus labrax* (Linnaeus, 1758), flounder, *Platichthys flesus* (Linnaeus, 1758), and sole, *Solea solea* (Linnaeus, 1758) are the most abundant marine fish whose juveniles use the Mondego estuary as a nursery area (Leitão et al., 2007; Martinho et al., 2007), similarly to other European estuarine systems (Aprahamian and Barr, 1985; Lagardère, 1987; Fonds et al., 1992; Cabral, 2000; Cabral and Costa, 2001). The specific objectives of this paper were to analyse the way the Mondego estuary functions as a nursery ground for 0-group sea bass, flounder and sole through the fish responses in terms of estuarine colonization, population structure, growth, feeding ecology and trophic niche overlap. Knowledge on the ecology of these species in southern European estuaries is scarce, specifically in the case of stressed areas like the Mondego estuary, which has been subjected to intense organic enrichment (Pardal et al., 2000). This environmental pressure may have a major impact on habitat quality for these juvenile fish, decreasing the abundance and biomass of benthic fauna as a consequence of hypoxic or anoxic conditions (Pardal et al., 2000).

**MATERIALS AND METHODS**

**Study area**

The Mondego River estuary (40°08’N, 8°50’W) is a small intertidal estuary located in the western coast of Portugal (Figure 1). In the upstream areas, about 7 km of the coast, it divides itself in two arms, north and south, that join again near the mouth. The two arms have very different hydrological features: the north arm is deeper (5 to 10 m during high
tide, tidal range 2 to 3 m), while the south arm (2 to 4 m deep, during high tide) is almost silted up in the upstream areas, causing the freshwater of the river to flow mainly by the north arm. A small freshwater input is carried out in the southern arm through the Pranto River, a small tributary system, which is regulated by a sluice according to the water needs in the surrounding rice fields. In the south arm, about 75% of the total area consists of intertidal mudflats, while in the northern arm this value is less than 10%.

The main environmental pressures in the Mondego estuary are: a) dredging and shipping in the north arm and b) raw sewage disposal and high nutrient inputs from agricultural and fish farms in the upstream areas of the south arm. Combined with a high water residence time, this led to an eutrophication process, resulting in macroalgae blooms of Enteromorpha spp. over the past two decades (Pardal et al., 2000; Dolbeth et al., 2003). However, the most downstream areas still remain relatively unchanged, exhibiting Zostera noltii meadows.

Sampling procedures

Sampling in the Mondego estuary (Figure 1) was carried out monthly, at five stations (M, N1, N2, S1, S2), between June 2003 and June 2004. Fishing took place during the night at high water of spring tides, using a 2 m beam trawl with one tickler chain and 5 mm mesh-size in the cod end. Three trawls were towed for an average of 5 minutes each on all sampling stations, covering at least an area of 500 m². Additionally, in June 2003, October 2003, January 2004 and June 2004, three hauls of about 15 minutes each, were performed at stations M, N1 and N2 using a 10 m bottom otter trawl (10 mm mesh size) (this gear could not be operated in stations S1 and S2, due to constrains imposed by the
shallow depth in these areas). Both fishing techniques were performed approximately at the speed of 1 knot, along the current. All fish caught were identified, counted, measured (total length to the nearest 1mm) and weighed (wet weight with 0.01 g precision). Data from the replicates of each station were added to form one sample. Density values were estimated based only on beam trawl data. Hydrological records (bottom water temperature, salinity and dissolved oxygen) were obtained during the fishing campaigns.

Population structure and growth

Population structure and growth rates were estimated by tracking recognizable cohorts from successive sampling dates through size frequency distribution analysis, performed by ANAMOD software package (Nogueira, 1992).

Absolute growth rates (AGR) were determined only for 0-group fish as:

$$\text{AGR} = \frac{L_{t_2} - L_{t_1}}{t_2 - t_1},$$

where $L_{t_2}$ and $L_{t_1}$ are the total length at time $t_2$ and $t_1$, respectively.

Feeding ecology

The diet of 0-group D. labrax (n=324), P. flesus (n=204) and S. solea (n=304) was studied based only on the stomach contents, which were removed and preserved in 4% buffered formalin for later identification to the lowest possible taxonomical level. Each prey item was counted and weighted (wet weight with 0.001 g precision). The relative importance of preys was assessed using the numerical (NI), occurrence (OI) and gravimetric (GI) indices (Hyslop, 1980), and feeding activity was evaluated using the vacuity index (VI), given by the percentage of empty stomachs.
Diet overlap was evaluated by Schoener’s Index: \( I_s = 1 - 0.5 \left( \sum_{i=1}^{n} |p_{i_A} - p_{i_B}| \right) \), where \( p_{i_A} \) and \( p_{i_B} \) are the numerical frequencies of item \( i \) on the diet of species \( A \) and \( B \), respectively (Linton et al., 1981). Although there are no critical levels for this index, Wallace and Ramsey (1983) suggested that values higher than 0.6 should be considered as biologically significant.

RESULTS

Environmental conditions in the Mondego estuary

Temperature and salinity showed a typical pattern for a southern temperate region, with summer values in the range 18-26°C and mild winter temperature. Both the highest temperature, 26°C in July 2003, and the lowest, 10°C in January 2004, were recorded in the shallow-water area of Station S2 (Figure 2). During the 2003 sampling series, salinity was highly variable in all stations, except in the upstream Station N2. A salinity gradient characterized the estuary from Station N2, under freshwater influence, to the mouth of the estuary – Station M, where the highest salinities were recorded. However, in 2004 there was a clear increase in salinity on all sampling stations. Dissolved oxygen showed a seasonal pattern, with lowest values in the summer and highest in the winter. In general, stations S2 and N2 presented the lowest oxygen concentrations. For further details on the environmental characteristics of the sampling stations, see Martinho et al. (2007).

Estuarine colonization and population structure
D. labrax was the most abundant species throughout the study, with 0-group maximum densities reaching 320 ind.1000 m\textsuperscript{-2} (Figure 3). P. flesus and S. solea 0-group fish presented lower densities, with maximum values of 30 and 23 ind.1000 m\textsuperscript{-2}, respectively (Figure 3). High variability in densities between years was registered for all species. The estuarine colonization started in June for D. labrax, in April for P. flesus, whereas S. solea started to colonize the estuary in late January. Four cohorts of D. labrax were recognised in June 2003, with C1, C2 and C3 for the 2-, 1- and 0-groups, respectively (Figures 4, 5). Observed at the end of the survey, the C4 was relative to newly 2004 0-group. For P. flesus and S. solea, only three cohorts were found between June 2003 and June 2004, with C1 and C2 representing 1- and 0-groups, respectively, and C3 the newly 2004 group.

Growth

The growth rates of 0-group fish were calculated based on the modal progression analysis (Figure 5). Sea bass growth rates presented an average growth rate of 0.24 mm d\textsuperscript{-1} and maximum value of 0.65 mm d\textsuperscript{-1}. From June 2003 to May 2004, 0-group fish size increased from 41.9 mm to 111.3 mm. For 0-group flounder, the maximum growth rate was 0.91 mm d\textsuperscript{-1}, with an average value of 0.20 mm d\textsuperscript{-1}. From June 2003 to April 2004, mean total length ranged from 78.6 mm to 132.8 mm. The average growth rate of juvenile soles was 0.44 mm d\textsuperscript{-1}, with a maximum value of 0.90 mm d\textsuperscript{-1}. From June 2003 to December 2003, mean total length increased from 77.7 mm to 168.1 mm.

Feeding ecology
Diet of 0-group sea bass consisted mainly of crustaceans, polychaetes and molluscs (Table 1). Copepoda, Amphipoda (mainly *Corophium* spp.) and Decapoda (mainly *Crangon crangon*) were the most important preys in number (NI=53%), occurrence (OI=42%) and weight (GI=34%), respectively. Polychaeta was the second most important prey according to the three indices (NI=31%; OI=35%; GI=22%), Mollusca (mainly represented by siphons of *Scrobicularia plana*) were also important in number and occurrence, and Teleostei in weight.

The main prey of 0-group flounder was *Corophium* spp. (indices values higher than 72%), followed by Polychaeta (NI = 9%, OI = 23% and GI = 17%), Isopoda (mainly *Cyathura carinata*) and Decapoda (especially *C. crangon*) (Table 1).

Sole juveniles fed mostly on Polychaeta (NI=81%, OI=69% and GI=65%). Amphipoda (mainly *Corophium* spp.), Teleostei, Mollusca (especially siphons of *S. plana*) and Decapoda (mainly *C. crangon*) were also important prey items in soles’ diet, although with lower indices values when compared to Polychaeta (Table 1). Feeding activity, given by the percentage of empty stomachs (Vacuity Index, VI), was higher in *D. labrax* and lower in *S. solea*. Dietary overlap between the three species was low (all $I_S$ values were lower or equal to 0.45) (Table 2).

**DISCUSSION**

*Sampling methodological approach*

In the present work, two sampling methodologies were used: a beam trawl and a bottom otter trawl, with different fishing efforts (beam trawl – monthly; otter trawl – every three months). While the beam trawl is easier to operate and to estimate densities (since the
area for catchment is constant), providing a good base for monthly/regular sampling of estuarine fish species, the otter trawl, gifted with a wider area for catchment, can be used for sampling larger specimens, that can easily escape the beam trawl (Fig. 6). Also, and according to Hemingway and Elliott (2002), beam trawl is an effective and appropriate method for collection of live specimens (and subsequent stomach analysis). Thus, it is suggested that otter trawl can be used as a complement for beam trawl surveys.

Growing season

The timing for settlement relies on the species’ spawning period, the spawning ground location and the duration of the pelagic life. In the Mondego estuary, located in the southern areas of the geographic distribution for *D. labrax*, *P. flesus* and *S. solea*, the range of temperatures over the studied period covered 10-26° C. Temperature may act on fish growth and habitat use by promoting higher growth rates and/or higher length of the growing season, providing a production of prey liable to sustain fish requirements. The growth rates determined for the three species in the Mondego estuary were within the range of the values reported for other European estuaries (Table 3), although non maximal, at least for sole, as demonstrated by rearing experiments (see Van der Veer et al., 2001).

Throughout south-western Europe, mean total lengths of *D. labrax* juveniles at the end of their first year were similar, with values of 173 mm and 181 mm reported in the Tagus estuary (Portugal) (Cabral and Costa, 2001) and South Spain (Arias, 1980), respectively. These values were higher than those obtained for the Mondego estuary, with an estimated size of 100 mm at the same age (Table 3). This can be a consequence of the particular conditions of the Mondego estuary, mainly its small area (3.4 km²) and high
freshwater influence, inducing an earlier migration to the adjacent coastal areas by the largest fish since the end of summer, as observed by a decrease in mean length. For older fish, the results suggest that migration pulses can also occur throughout the year.

Regarding *P. flesus* juveniles, growth studies are scarce. However, differences in mean total length with those reported for the Wadden Sea (Lake Grevelingen) (Doornbos and Twisk, 1984) were found, since the individuals from the Mondego exhibited longer total lengths at the end of the fast growing season (Table 3). A migration pattern by the largest 0-group individuals was also observed, occurring only in the end of winter.

*S. solea* 0-group juveniles showed a marked latitudinal pattern in fish size. By the end of the fast growing season (end of autumn), in the northern areas, the mean total length varied from 90 mm to 115 mm, for the United Kingdom and Wadden Sea, respectively. In the southernmost areas, the mean length of sole juveniles ranged from 166 mm to 173 mm, for Portugal and South Spain, respectively. Cabral (2003) suggested that these differences, leading to a larger fish size in the southernmost areas, may rely on higher growth rates during a longer fast growing season. The mean total length for this species in the Mondego (168.1 mm) was within the range for its geographical area (Table 3).

Winter temperature was not yet limiting for sole. Fonds and Rijnsdorp (1988) data's predicted a maximum AGR of 0.25 mm per day at 10° C and under the summer max (26° C), growth is predicted to be maximal (AGR = 1.6 mm per day) but it reaches the asymptote (see Van der Veer et al., 2001). According to Lefrançois and Claireaux (2003), the optimum temperature for metabolic scope for 1-year sole is 18.8° C, which combined with different food composition and availability (Van der Veer et al., 2001) and additional energy expenditures, probably results in non maximal growth, at least for sole. Bigger total
lengths than those measured in northern countries are also a result of a longer growing season.

Population structure and estuarine colonization

Distinct periods of estuarine colonization were observed. *S. solea* juveniles were the first to enter the estuary, in late January. This early colonization likely reflects a winter spawning period and a shorter pelagic life due to warmer waters in this area than northwards. In the Bay of Biscay, sole spawn from winter to spring at sea-water temperature around 8-9° C (Koutsikopoulos and Lacroix, 1992) and settlement is completed in late spring (Amara et al., 1994). Differences in the onset of colonization by sole in neighbour estuaries (Mondego and the Tagus) may be attributed to the wintering conditions and fluvial regime of each estuarine system (Le Pape et al., 2003) or to between-year climate induced variations (Cabral and Costa, 2001; Van der Veer et al., 2001).

*D. labrax* and *P. flesus* entered the estuary in late and early spring, respectively, as they are spring spawners (Van der Veer, 1985; Jennings and Pawson, 1992). By the end of the second year, all species carried out a seawards migration. In the following year(s) they returned to the estuary sporadically, as supported by the few older individuals caught occasionally at the mouth of the estuary, mainly in the otter trawl surveys. For the three species, only one annual cohort was found. This clearly contrasts with results obtained for other southern estuaries, namely the Tagus estuary (Cabral, 2003) and Ria Formosa (Andrade, 1992), where two distinct cohorts of 0-group juveniles of *S. solea* were described. This pattern can be attributed to an oceanographic boundary south to the
Mondego, the Peniche Peninsula, which is the northern limit for Mediterranean influence and the southern limit for North-Atlantic influence (Fiúza, 1982).

In the Bay of Biscay, the three species spawn roughly at the same season (winter-spring, depending on wintering conditions). Estuarine conditions resulted in non maximal growth rates for sole (and may be for the flounder), but a protracted growing season and food availability allowed 0-groups to reach big sizes before winter, contrary to the typical pattern of offshore emigration that occurs at higher latitudes.

All species showed a high variability in densities, which could be the result of inter-annual variations in recruitment strength (caused by either density-dependent or density-independent factors), that affect or promote recruitment and settlement of fishes in estuaries (Cabral et al., 2007).

*Nursery functioning*

Diet analysis showed that 0-group sea bass fed mostly on Crustacea, Polychaeta and Mollusca, as outlined in other studies (Arias, 1980; Aprahamian and Barr, 1985; Cabral and Costa, 2001). The most significant difference that can be observed when comparing results from other geographical areas is the low importance of Mysidacea in the diet of juveniles in the Mondego estuary. This clearly contrasts with the results reported by Arias (1980) for the Mediterranean, and by Cabral and Costa (2001) for the Tagus estuary, and may be due to a lower abundance of mysids in the Mondego estuary.

Flounder 0-group juveniles ate chiefly *Corophium* spp., which is the most abundant invertebrate species in the upstream areas colonized by this species (Martinho et al., 2007). Polychaetes, isopods and decapods were lesser important preys. Similar results were
obtained by Aarnio et al. (1996), in which amphipods and mysids composed most of the diet of 0-group flounders caught in the northern Baltic Sea. The preference for mobile and active prey, such as amphipods, was outlined by De Groot (1971), as this species is essentially a visual feeder.

The diet of juvenile soles consisted mainly of Polychaeta, being also important items Amphipoda, Mollusca and Decapoda. These feeding habits were similar to the ones described in the Tagus estuary, being the most important items Polychaeta and Amphipoda, particularly Corophium spp. (Cabral, 2000). This similarity can be attributed to the similar nursery and feeding grounds (mainly intertidal mudflats) occupied by this species in both estuaries.

The present results of the diet composition are consistent with the ones for other European estuaries (e.g. Arias, 1980; Aprahamian and Barr, 1985; Lagardère, 1987; Fonds et al., 1992; Aarnio et al., 1996; Cabral, 2000; Cabral and Costa, 2001; Hampel et al., 2005), reflecting mainly the available benthic fauna and emphasizing the generalist and opportunistic behaviour of these species. Analysis of trophic niche overlap showed that these species most likely did not compete directly for food. Partitioning of the available resources by the likely competitors is most probably prevented by an abundant food supply (Costa et al., 2002) and in agreement, the Mondego estuary appears to be a very productive system when compared to other tidal flats (Dolbeth et al., 2003). In addition, the observed spatial and temporal segregation between the three species seems to prevent direct competition, favouring a better partitioning of the available resources (Cabral et al., 2007), as observed in more northern systems (e.g. Hampel et al., 2005).
In conclusion, the nursery functioning greatly depends on the geographic area: in northern ecosystems an earlier cooling of coastal waters and estuarine habitats due to freshwater runoffs, set fish to disperse offshore from late summer onwards (Henderson and Seaby, 2005). The present results showed that milder conditions of southernmost estuaries allow fish to stay over winter inshore, probably protracting the growing season. In the Mondego estuary, this may also rely on the improvements of the global ecological quality due to a recovery of seagrass beds and the associated benthic fauna due to the implementation of eutrophication mitigation measures (Pardal et al., 2000; Dolbeth et al., 2003), thus increasing the carrying capacity of the whole system.

ACKNOWLEDGEMENTS

The authors are indebted to the IMAR for funding and support and to all colleagues who assisted in field work and particularly to Marina Dolbeth and Heliana Teixeira for the help with the identification of stomach contents. This work was partially supported by III - Instituto de Investigação Interdisciplinar - Universidade de Coimbra, Research Project III/AMB/4/2005. The authors also wish to acknowledge the comments and suggestions of both the referees and the editor, who improved greatly the final manuscript.

REFERENCES


Table 1. Relative importance of prey items on the diet of *D. labrax* (n=324), *P. flesus* (n=204) and *S. solea* (n=304), according to the numeric (NI), occurrence (OI) and gravimetric (GI) indices (ni – not identified items; VI - Vacuity index).

<table>
<thead>
<tr>
<th>Prey item</th>
<th><em>D. labrax</em></th>
<th><em>P. flesus</em></th>
<th><em>S. solea</em></th>
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<tr>
<td></td>
<td>NI</td>
<td>OI</td>
<td>GI</td>
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<tr>
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<td>3.70</td>
<td>24.01</td>
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<td>Abra alba</td>
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<td>-</td>
<td>-</td>
</tr>
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<td>-</td>
<td>-</td>
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<tr>
<td>Idoteidae ni</td>
<td>0.04</td>
<td>1.79</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Isopoda ni</td>
<td>Amphipoda</td>
<td>Decapoda</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td></td>
<td>0.02  0.72  0.03</td>
<td>6.74  42.29  14.16</td>
<td>2.23  27.24  33.65</td>
</tr>
<tr>
<td></td>
<td>- - -</td>
<td>87.79  94.74  72.14</td>
<td>3.00  3.29  2.87</td>
</tr>
<tr>
<td></td>
<td>- - -</td>
<td>6.99  17.82  3.34</td>
<td>0.89  5.45  20.51</td>
</tr>
<tr>
<td></td>
<td>- - -</td>
<td>11.39  2.75</td>
<td>17.64</td>
</tr>
<tr>
<td></td>
<td>- - -</td>
<td>0.03  0.72  0.03</td>
<td>0.32  2.97  0.57</td>
</tr>
</tbody>
</table>
Table 2. Schoener Index values between 0-group *D. labrax*, *P. flesus* and *S. solea* in the Mondego Estuary nursery areas, indicating diet overlap between species (values above 0.6 are considered as biologically significant).

<table>
<thead>
<tr>
<th></th>
<th><em>D. labrax</em></th>
<th><em>P. flesus</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. flesus</em></td>
<td>0.18</td>
<td>-</td>
</tr>
<tr>
<td><em>S. solea</em></td>
<td>0.45</td>
<td>0.19</td>
</tr>
</tbody>
</table>
Table 3. Mean total length (mm) and absolute growth rate (AGR) (mm d\(^{-1}\)) maximum values of 0-group *D. labrax*, *P. flesus* and *S. solea* at the end of the fast growing season, according to the geographical area.

<table>
<thead>
<tr>
<th>Species</th>
<th>Geographical area</th>
<th>Total length (month)</th>
<th>AGR</th>
<th>Author(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>D. labrax</em></td>
<td>United Kingdom, South Wales Coast</td>
<td>-</td>
<td>0.60</td>
<td>Jennings et al., (1991)</td>
</tr>
<tr>
<td><em>D. labrax</em></td>
<td>Portugal, Aveiro Lagoon</td>
<td>170 (December)</td>
<td>-</td>
<td>Gordo (1989)</td>
</tr>
<tr>
<td><em>D. labrax</em></td>
<td>Portugal, Mondego Estuary</td>
<td>111 (December)</td>
<td>0.65</td>
<td>Present study</td>
</tr>
<tr>
<td><em>D. labrax</em></td>
<td>Portugal, Tagus Estuary</td>
<td>173 (November)</td>
<td>1.53</td>
<td>Cabral and Costa (2001)</td>
</tr>
<tr>
<td><em>D. labrax</em></td>
<td>Spain, San Pedro Estuary (Cádiz)</td>
<td>181</td>
<td>-</td>
<td>Arias (1980)</td>
</tr>
<tr>
<td><em>D. labrax</em></td>
<td>Morocco, Atlantic Coast</td>
<td>-</td>
<td>0.83</td>
<td>Gravier (1961)</td>
</tr>
<tr>
<td><em>P. flesus</em></td>
<td>Netherlands, Lake Grevelingen</td>
<td>110</td>
<td>-</td>
<td>Doornbos and Twisk (1984)</td>
</tr>
<tr>
<td><em>P. flesus</em></td>
<td>Portugal, Mondego Estuary</td>
<td>125 (November)</td>
<td>0.91</td>
<td>Present study</td>
</tr>
<tr>
<td><em>S. solea</em></td>
<td>Wadden Sea, Ems Estuary</td>
<td>115 (October)</td>
<td>1.95</td>
<td>Jager et al. (1995)</td>
</tr>
<tr>
<td><em>S. solea</em></td>
<td>United Kingdom, North Wales Coast</td>
<td>90 (October)</td>
<td>0.57</td>
<td>Rogers (1994)</td>
</tr>
<tr>
<td><em>S. solea</em></td>
<td>France, Loire Estuary</td>
<td>110 (December)</td>
<td>-</td>
<td>Desaunay (1981)</td>
</tr>
<tr>
<td><em>S. solea</em></td>
<td>Portugal, Mondego Estuary</td>
<td>168 (December)</td>
<td>0.90</td>
<td>Present study</td>
</tr>
<tr>
<td><em>S. solea</em></td>
<td>Portugal, Tagus Estuary</td>
<td>166 (October)</td>
<td>1.51</td>
<td>Cabral (2003)</td>
</tr>
<tr>
<td><em>S. solea</em></td>
<td>Spain, Castellón Coast</td>
<td>173 (December)</td>
<td>-</td>
<td>Ramos (1982)</td>
</tr>
</tbody>
</table>
FIGURE LEGENDS

Figure 1 – The Mondego estuary and the location of the 5 sampling stations (A–E) (2003-2004).

Figure 2 – Monthly variation of (A) temperature (°C), (B) salinity and (C) dissolved oxygen (mg L⁻¹) in the Mondego estuary during the period of June 2003 to June 2004.

Figure 3 - Monthly variation of 0-group *D. labrax* (A), *P. flesus* (B), *S. solea* (C) per 1000 m² (based on beam trawl surveys).

Figure 4 – Size frequency distribution of (A) *D. labrax*, (B) *P. flesus* and (C) *S. solea* populations. Arrowheads indicate the identified cohorts (C); N indicates the total number of measured individuals.

Figure 5 – Variation of mean fish length (± standard deviation) during the study period, for each cohort identified for juvenile (A) *D. labrax*, (B) *P. flesus* and (C) *S. solea*.

Figure 6 – Comparison between the average total length of *D. labrax*, *P. flesus* and *S. solea*, captured with different fishing methodologies: beam and otter trawl.
Figure 1
Figure 2

A. Temperature °C

B. Salinity

C. Oxygen mg L⁻¹

Month: DJFMAMJ

Year: 2003 2004
Figure 5

A

B

C

SEAWARDS MIGRATION

Total length (cm)

Total length (cm)

Total length (cm)

J J A S O N D F M A M J

J J A S O N D F M A M J

J J A S O N D F M A M J

C1

C2

C3

C4

C1

C2

C3

0

5

10

15

20

25

30

35

40

J J A S O N D F M A M J

J J A S O N D F M A M J

J J A S O N D F M A M J

2003 2004
Figure 6

The bar chart shows the total length (cm) of three species: *D. labrax*, *P. flesus*, and *S. solea*, caught by two different trawl methods: Beam trawl and Otter trawl.

- **D. labrax**:
  - Beam trawl: 2239 cm
  - Otter trawl: 203 cm
- **P. flesus**:
  - Beam trawl: 368 cm
  - Otter trawl: 210 cm
- **S. solea**:
  - Beam trawl: 358 cm
  - Otter trawl: 341 cm