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Relative importance of estuarine flatfish nurseries along the Portuguese coast

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Abstract

The relative importance of nursery areas and their relationships with several environmental variables were evaluated in nine estuarine systems along the Portuguese coast based on trawl surveys. Historical data were used to outline changes and trends in the nursery function of some of these estuaries over the past decades. The dominant flatfish species in Portuguese estuaries were *Platichthys flesus* (Linnaeus, 1758), *Solea solea* (Linnaeus, 1758), *Solea senegalensis* Kaup, 1858 and *Monochirus hispidus* Rafinesque, 1814, but their occurrence differed among the estuaries. *P. flesus* only occurred in estuaries north of the Tejo estuary (39°N), *S. solea* was quite rare along the southern Portuguese coast (south of 37°30′N), *S. senegalensis* occurred in estuaries throughout the coast, but its abundance varied considerably, and the occurrence of *M. hispidus* was limited to the Sado estuary and Ria Formosa. A Correspondence Analysis was performed to evaluate the relationships between flatfish species abundance and geomorphologic and hydrologic characteristics of estuaries (latitude, freshwater flow, estuarine area, intertidal area, mean depth and residence time). Abiotic characteristics (depth, temperature, salinity, sediment type) of nursery grounds of each flatfish species were also evaluated. Results showed that some estuaries along the Portuguese coast have nursery grounds used by several flatfish species (e.g. Ria de Aveiro, Sado estuary), while in other systems a segregation was noticed, with juveniles of different species occurring in distinct estuarine areas (e.g. Minho and Mondego estuaries). This emphasizes the relevance of niche overlap, but the potential for competition may be considerably minimized by differences in resource use patterns and by an extremely high abundance of resources. Peak densities of flatfishes recorded in nurseries areas along the Portuguese coast were within the range of values reported for other geographical areas. Inter-annual abundance variability of all the species in the Tejo and Sado estuaries was extremely high, with a drastic decrease in *P. flesus* in the Tejo estuary, probably related to higher water temperature in recent years due to global climate change.

Keywords: Flatfish; Nursery areas; Estuaries; *Solea solea*; *Solea senegalensis*; *Platichthys flesus*; *Monochirus hispidus*

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1. Introduction

The importance of estuarine systems as nursery areas for flatfishes has been emphasized worldwide (e.g. Zijlstra, 1972; Cyrus and Martin, 1991; Cabral and Costa, 1999; Cabral, 2000a; Riou et al., 2001; Able et al., 2005). In the North Atlantic, the most abundant and commercially important flatfishes present a life history pattern with several common features, such as spawning in the continental shelf, egg and larval migration towards coastal areas through passive and active processes and concentration in particular estuarine and/or shallow marine areas (e.g. Zijlstra, 1972; Bergman et al., 1988; Deniel, 1984; Rijnsdorp et al., 1985; Marchand and Masson, 1988, 1989; Koutsikopoulos and Lacroix, 1992). The use of these coastal environments by juvenile fish usually presents several advantages such as high prey availability, refuge from predators and good conditions for a rapid growth (Bergman et al., 1988; Haedrich, 1983; Miller et al., 1985; Lenanton and Potter, 1987; Beck et al., 2001).

The distribution and abundance of juveniles within nursery habitats have been related to several abiotic and biotic factors, such as salinity, temperature, sediment type, prey and predator abundance, considered as some of the most important governing flatfish distribution, but their preponderance may be quite different according to geographical area. Studies on north-eastern Atlantic flatfish juveniles have shown that the abundance of *Solea solea* (Linnaeus, 1758) may be either associated with oligo- or mesohaline areas (Dorel et al., 1991; Marchand, 1993; Cabral and Costa, 1999) or with more saline areas (Pihl, 1989; Dorel and Desaunay, 1991; Rogers, 1994), and they may occur in high densities in grounds with a wide variety of sedimentary types (Dorel and Desaunay, 1991; Dorel et al., 1991; Rogers, 1994; Cabral and Costa, 1999). For *Platichthys flesus* (Linnaeus, 1758), another abundant flatfish in North European estuaries, inconsistencies in the relationship between abundance and environmental factors have also been reported: salinity (Kerstan, 1991; Jager, 1998; Power et al., 2000; Vinagre et al., 2005), sediment type (Gibson and Robb, 1992; Gibson, 1994; Amezcua and Nash, 2001; Vinagre et al., 2005) and dissolved oxygen concentration (Bos, 1999; Power et al., 2000).

Along the Portuguese coast, more than 25 flatfish species occur (Albuquerque, 1956; Cabral, 2002). This species richness is higher than that generally found in Northern Europe and similar to that found in Mediterranean, since many flatfish species have their southern and northern distribution limits along the Portuguese coast (Desoutter, 1997; Cabral, 2002). The zoogeographic importance of this latitudinal area has long been recognized, representing the transition between north-eastern Atlantic warm-temperate and cold-temperate regions (Ekman, 1953; Briggs, 1974). Consequently, several species are found in sympatry in this geographical area, which constitutes an interesting and unique ecological context. Previous studies on flatfish nursery areas conducted along the Portuguese coast have explored the distribution and abundance patterns of flatfish species with northern and southern affinities (e.g. Cabral and Costa, 1999; Cabral, 2000a; Amaral and Cabral, 2004; Vinagre et al., 2005).

Despite the large numbers of studies on habitat preferences by juveniles of some of these flatfish species, few have focused on variation in a small-scale geographical range. In the present paper, we analyse the importance of nine estuarine systems along the Portuguese coast for juvenile flatfish and evaluate the relationships between species abundance and environmental conditions in these nursery grounds. Our study presents an integrative perspective of habitat requirements of flatfish juveniles and the structuring factors within nursery areas.

2. Material and methods

2.1. Study areas

Nine estuarine systems along the Portuguese coast were considered in this study (Fig. 1). Geomorphologic and hydrologic characteristics differ considerably according to estuarine system (Table 1). The Tejo and the Sado estuaries are much larger than the others. The Mira estuary, with its channel-like shape, is the smallest, covering an area of ca. 4 km^2. Ria de Aveiro and Ria Formosa are shallow coastal lagoon systems with large intertidal areas. Mean depth varies between 1.0 and 5.1 m, which indicates that shallow areas predominate in all estuaries. River flow differs markedly: the Minho, Douro and Tejo have mean flow values higher than 300 m^3 s^{-1}, contrasting with low freshwater flow estuaries such as the Mira and Ria Formosa.

2.2. Data collection and data analysis

Data on juvenile flatfish densities in Portuguese estuarine nursery areas were obtained from different studies conducted between 1990 and 2004 (see Table 1). These studies used similar trawl sampling techniques, widely used in flatfish surveys, and have a broad spatial collection of samples throughout each estuary. Data were obtained in similar conditions to diminish the

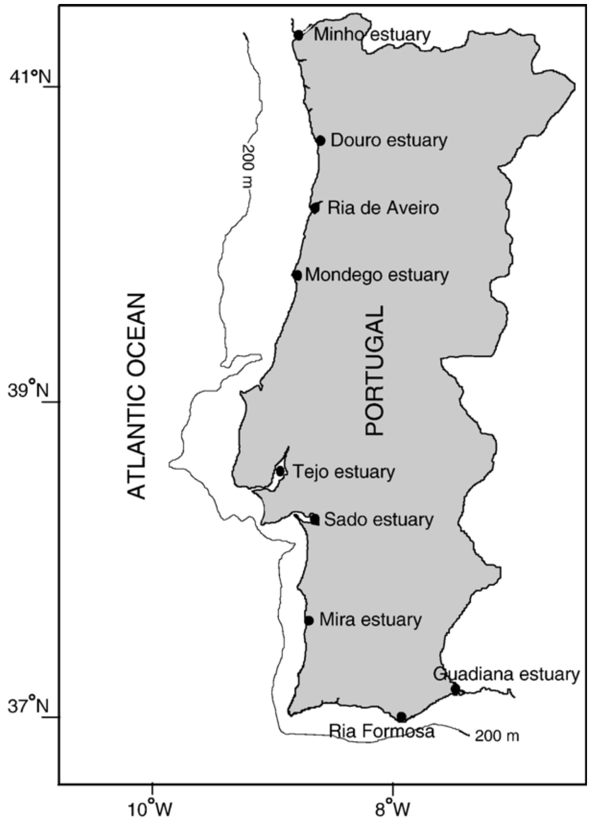

Fig. 1. Location of the nine studied estuaries along the Portuguese coast.

effect of sampling in the results. The minor differences amongst the trawls are mostly related to the physical conditions of each particular estuary, namely beam size, while mesh sizes were equal. All the studies considered in the present work were based in a wide spatial and temporal coverage of sampling surveys (at least one year of monthly or bimonthly campaigns). Densities were expressed as the number of individuals per 1000 m^2.

A set of environmental variables were used to characterize each estuary: total area (km^2), intertidal area (in percentage), mean depth (m), freshwater flow ($m^3\ s^{-1}$), residence time (days) and latitude. These data were obtained from nautical maps, from the Portuguese Water Resources Institute (Instituto da Água) and from a hydrological model (MOHID) developed by Neves (1985).

In order to determine the general patterns of flatfish abundance according to nursery area, a Correspondence Analysis (CA) was performed using Canoco (Ter Braak, 1995). Data on geomorphologic and hydrologic characteristics of each estuary were used as a co-variable data matrix.

The location and environmental conditions of the major nursery grounds within each estuarine system were also compared by a Principal Components Analysis (PCA). This analysis aimed to outline the main similarities among nursery grounds and to evaluate differences in environmental conditions between nurseries. The PCA was based on the correlation matrix of environmental characteristics, since variables were measured on different scales. The abiotic variables considered in this analysis, e.g. water temperature, salinity, depth and percentage of fine sand and mud in the sediment, were obtained from the studies reported in Table 1 and also from unpublished data. Since these variables vary considerably according to tidal cycle and season, range midpoint values, calculated based on the range of variation reported for each nursery ground, were used in the analysis. Differences in peak abundances reported for *Solea solea*, *Solea senegalensis* Kaup, 1858, and *Platichthys flesus* nursery grounds were evaluated using a Kruskal-Wallis test. These analyses were performed in Statistica 6.0, and a significance level of 0.05 was considered.

The interannual variability of juvenile abundance was determined for estuarine systems where density

Table 1
Peak densities (ind 1000 m^{-2}) reported for *P. flesus*, *S. solea*, *S. senegalensis* and *M. hispidus* and main geomorphologic and hidrologic characteristics in several estuarine systems along the Portuguse coast (Data sources: 1 - Sousa et al., 2005; 2 - Vinagre et al., 2005; 3 - Rebelo, 1993; 4 - unpubl. data; 5 - Martinho, 2005; 6 - Cabral and Costa, 1999; 7 - Cabral, 2000a; 8 - Costa, 2004; 9 - Erzini, 2002; 10 - Bexiga, 2002)

Estuary	Minho [1,4]	Douro [2]	Ria de Aveiro [3,4]	Mondego [5]	Tejo [6]	Sado [7]	Mira [4,8]	Ria Formosa [4,9]	Guadiana [4,10]
P. flesus	236.0	9.1	4.7	30.0	0.0	0.0	0.0	0.0	0.0
S. solea	67.0	8.0	2.2	23.1	25.9	24.5	15.7	0.0	0.0
S. senegalensis	0.0	0.0	1.9	0.0	61.6	3.1	0.0	4.1	0.5
M. hispidus	0.0	0.0	0.0	0.0	0.0	32.4	0.0	0.2	0.0
Total area (km^2)	23.0	7.8	96.5	9.8	325.0	174.7	4.1	72.2	20.3
Intertidal area (%)	9.0	11	87	64	40	44	42	81	24
Mean depth (m)	2.6	4.2	2.0	2.0	5.1	6.0	4.0	1.0	3.1
River flow ($m^3\ s^{-1}$)	300	450	40	79	300	40	3	2	80
Residence time (days)	2	2	17	3	25	30	15	2	12

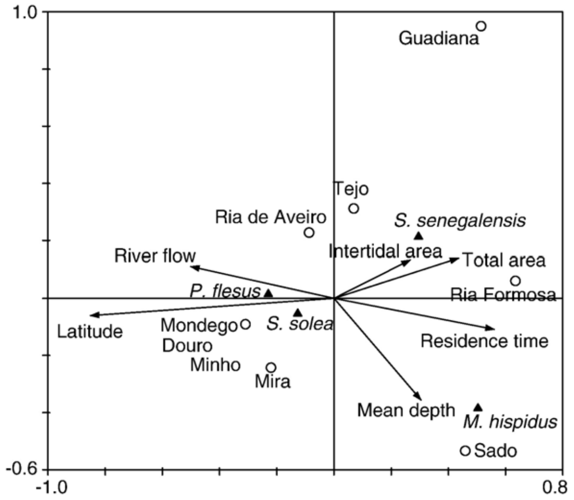

Fig. 2. Correspondence Analysis of flatfish species densities in the nine studied estuaries, with geomorphologic and hydrological variables as co-variables.

estimates were available for several years (Tejo and Sado estuaries). Comparison was based on mean densities in the month of higher abundance. For the Tejo estuary, data were available for 1978, 1979 and 1980 (Costa, 1982), 1988 (Costa and Bruxelas, 1989), 1994, 1995 and 1996 (Costa et al., 1998), 2000 and 2001 (Costa et al., 2002). Flatfish densities in the Sado estuary were obtained from studies conducted in 1987, 1988 and 1989 (Cunha, 1994), in 1994 and 1995 (Cabral, 2000a) and in 2000 (Cabral et al., unpubl. data).

3. Results

3.1. Relative importance of estuarine nurseries for flatfishes

The occurrence and abundance of flatfish juveniles differed considerably according to estuarine system (Table 1). *Platichthys flesus* only occurred in estuaries north of the Tejo estuary (39°N) and *Solea solea* was rare on the southern coast (south to 37°30′N). *Solea senegalensis* occurred in estuaries throughout the coast, but its abundance varied considerably. Occurrence of *Monochirus hispidus* Rafinesque, 1814, was limited to the Sado estuary and Ria Formosa. The CA performed to evaluate the relationships between flatfish abundance and estuarine geomorphologic and hydrologic characteristics accounted for 90.7% of the total variance in the first two ordination axes. The CA diagram showed that *P. flesus* and *S. solea* were more abundant in northern estuaries and were associated with high freshwater river flows (Fig. 2). *S. senegalensis* were particularly abundant in large estuaries with an extended intertidal area. *M. hispidus* was only caught in large numbers in the Sado estuary and was negatively correlated with freshwater flow (Fig. 2).

3.2. Environmental conditions of nursery grounds

The ordination pattern obtained in the PCA, performed with the environmental characteristics of the main flatfish nursery grounds, showed a high intra- and inter-species variability (Fig. 3). The first two axes of this ordination analysis accounted for 97.5% of the total variance. *P. flesus* nursery grounds were located in deep and low-salinity estuarine areas (Fig. 3, Table 2). The negative relationship with temperature is due to the latitudinal gradient of this species, which only occurs in northern estuaries, where water temperature is lower than in southern ones. The sediment characteristics in *P. flesus* nursery grounds were quite different according to estuarine system (Table 2). Some of the *S. solea* nurseries were characterized by a high content of fine sand in the sediment and by high water temperatures, while others were located in deeper areas (Tejo) and muddy grounds (Sado) (Fig. 3, Table 2). In most estuaries, *S. solea* nursery grounds were located in oligo- or mesohaline areas, except for the Minho and the Sado estuaries where juveniles of this species occur in more saline areas (Table 2). *S. senegalensis* nurseries

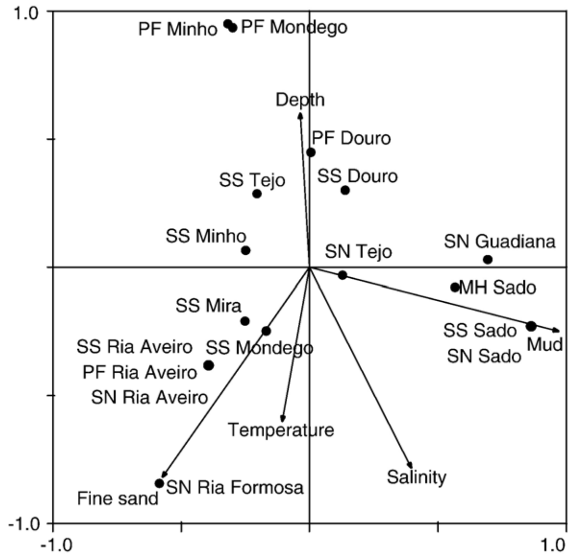

Fig. 3. Principal Component Analysis of flatfish species densities in the nine studied estuaries and environmental conditions at nursery areas. Flatfish estuarine nurseries are indicated by the name of the species (PF - *Platichthys flesus*, SS - *Solea solea*, SN - *Solea senegalensis*, MH - *Monochirus hispidus*) and estuary.

Table 2
Environmental conditions (salinity, temperature, depth and sediment composition) within the main flatfish nursery grounds in Portuguese estuaries (range mid-point values; range between brackets)

Estuary	Nursery ground for…	Salinity (‰)	Temperature (°C)	Depth (m)	% of mud in the sediment	% of fine sand in the sediment
Minho	*P. flesus*	0.0 (0.1-0.0)	15.8 (9.4-22.4)	2.5 (1.5-4.3)	0.29 (0.22-0.36)	0.27 (0.19-0.32)
	S. solea	31.0 (22.6-34.6)	14.4 (12.6-18.3)	2.6 (1.6-4.0)	12 (0.22-23)	25 (0.62-46)
Douro	*P. flesus*	16.7 (7.5-25.9)	15.7 (10.6-20.8)	6.9 (4.9-8.9)	23 (13-33)	9 (7-11)
	S. solea	15.4 (5.0-25.8)	15.6 (10.5-20.7)	5.5 (4.5-6.5)	34 (25-43)	12 (9-15)
Ria de Aveiro	*P. flesus*	20.8 (11.7-29.9)	17.3 (10.1-24.5)	1.7 (1.2-2.2)	15 (10-20)	50 (35-65)
	S. senegalensis	20.8 (11.7-29.9)	17.3 (10.1-24.5)	1.7 (1.2-2.2)	15 (10-20)	50 (35-65)
	S. solea	20.8 (11.7-29.9)	17.3 (10.1-24.5)	1.7 (1.2-2.2)	15 (10-20)	50 (35-65)
Mondego	*P. flesus*	2.1 (0.1-4.1)	17.2 (11.4-23.0)	4.5 (3.5-5.5)	2 (1-3)	1 (0-2)
	S. solea	22.7 (17.8-27.6)	18.0 (11.1-24.9)	2.4 (1.3-3.5)	25 (16-34)	39 (26-52)
Tejo	*S. senegalensis*	19.2 (9.2-29.2)	18.3 (9.6-27.0)	3.2 (1.7-4.7)	39 (18-60)	24 (11-37)
	S. solea	11.2 (5.3-17.1)	17.7 (10.9-24.5)	5.0 (3.1-6.9)	16 (12-20)	22 (16-28)
Sado	*M. hispidus*	32.0 (29.8-34.2)	17.5 (9.3-25.7)	2.0 (1.1-2.9)	80 (62-98)	12 (7-17)
	S. senegalensis	32.0 (29.8-34.2)	17.5 (9.3-25.7)	2.0 (1.1-2.9)	80 (62-98)	12 (7-17)
	S. solea	32.0 (29.8-34.2)	17.5 (9.3-25.7)	2.0 (1.1-2.9)	80 (62-98)	12 (7-17)
Mira	*S. solea*	20.0 (12.7-27.3)	17.5 (9.3-23.9)	3.0 (1.6-4.4)	20 (11-29)	40 (26-54)
Ria Formosa	*S. senegalensis*	30.0 (27.8-32.2)	22.0 (16.2-27.8)	2.0 (1.4-2.6)	10 (7-13)	70 (47-93)
Guadiana	*S. senegalensis*	17.3 (9.1-25.5)	17.5 (11.3-23.7)	2.0 (1.6-2.4)	70 (59-81)	10 (7-13)

were generally characterized by low depth and high salinity. The sediment in some of these nurseries had a high mud content, while others, such as Ria Formosa and Ria de Aveiro, had a high fraction of fine sands (Fig. 3, Table 2). *M. hispidus* nursery grounds were similar to the ones described for *S. solea* and *S. senegalensis* in the Sado estuary (Fig. 3), but data available for the Ria Formosa were not sufficient to consider it a nursery ground for this species.

3.3. Inter-species and inter-annual variability in flatfish juvenile densities

For the three most abundant species, i.e. *P. flesus*, *S. solea* and *S. senegalensis*, density estimates were not significantly different in the estuarine systems where they occurred ($H=2.08$, $P>0.05$). Nonetheless, mean peak densities of these species in Portuguese estuarine systems varied highly among sites: 72.0 (109.7) for *P. flesus*, 20.1 (22.6) for *S. solea* and 13.4 (27.0) for *S. senegalensis* (mean values and standard deviation between brackets).

Only for the Tejo and the Sado estuaries was it possible to evaluate the inter-annual variability of flatfish juveniles in nursery areas, because no historical data exist for the other estuaries. Although the available historical time-series data were fragmented, it was possible to evaluate both medium-term (decadal) and short-term (consecutive years) changes. For all species inter-annual variability was extremely high (Fig. 4). For *P. flesus* a decadal trend can be observed in the Tejo estuary: despite the high variability, its abundance has decreased to extremely rare since the early 1990s. For *S. solea*, *S. senegalensis* and *M. hispidus* such a trend was not evident, with high densities reported between 1994 and 1996 (Fig. 4). For these four

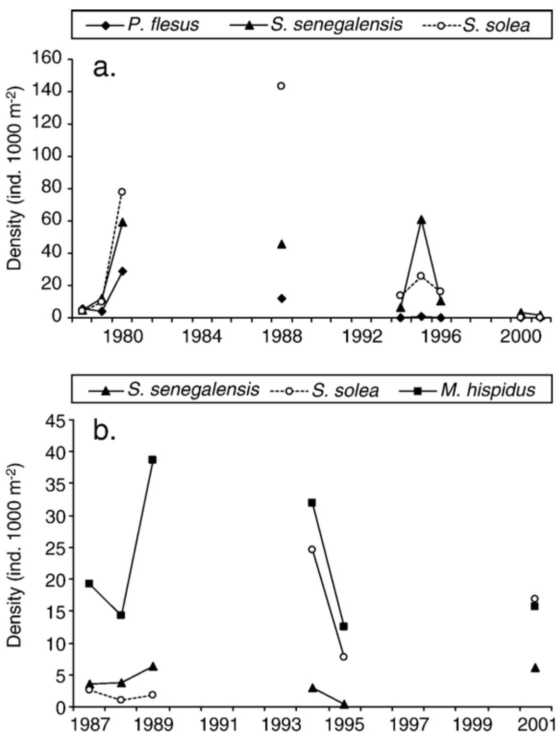

Fig. 4. Inter-annual variability of flatfish species densities in (a) the Tejo and (b) Sado estuaries.

most abundant species, there was some concordance in weak and strong juvenile recruitment years.

4. Discussion

It is generally accepted that estuaries are important nursery areas for several commercially important flatfish species. The present study shows that the importance varies according to species. Two main patterns were found: one caused by a latitudinal gradient and the other by specific habitat preferences. The latitudinal gradient was noticed for *Platichthys flesus* and *Solea solea*, which have their southern distribution limits along the Portuguese coast (Nielsen, 1986; Quéro et al., 1986). However, this gradient was not reflected in the abundance of these flatfishes, which differed greatly between nursery areas. For *Monochirus hispidus* and *Solea senegalensis*, we suggest that their occurrence was mainly due to specific habitat preferences. However, some latitudinal factors may also be responsible for their absence in northern estuaries, since these species are characteristic of southern areas, particularly *M. hispidus* (Quéro et al., 1986).

For *S. senegalensis* it was clearly shown that nursery grounds are limited to large estuarine systems with an extended intertidal area. Evidence of the use of tidal mudflat areas by this species has been reported for the Tejo estuary (Cabral, 2000b). Tidal mudflats are extremely rich in the major prey of *S. senegalensis* (Cabral, 2000b) and can also provide some of the advantages of estuarine habitat use by marine fishes, such as refuge from predators and favourable conditions for a rapid growth.

The other flatfish species that exhibited a particular occurrence throughout the Portuguese coast was *M. hispidus*. It only occurred in abundance in the Sado estuary and Ria Formosa. The common characteristics of these two estuarine systems are the extended high-salinity area as well as the diversified habitat structure, including boulder grounds and eelgrass beds (Cabral, 2000a). *M. hispidus* is probably a resident species in the Sado estuary (Cabral, 2000a), which clearly sets it apart from the other flatfish species considered in this study. Although most aspects of the ecology of *M. hispidus* remain unknown (Amaral and Cabral, 2004), its occurrence may be limited to estuarine systems that act as coastal bays, where the influence of freshwater flow is not particularly marked.

Despite the high variability in the abiotic characteristics within nursery grounds of the various estuaries, the present study shows that *P. flesus* and *S. solea* nurseries were usually located in lower salinity areas than the other species, which occurred in places with a wider range of environmental conditions.

Several authors have stressed the importance of salinity in *P. flesus* distribution and abundance patterns, pointing out that age 0-group fish prefer low-salinity waters, in contrast to older individuals, which are more widely distributed throughout estuaries (Kerstan, 1991; Jager, 1998). Vinagre et al. (2005) also confirmed this pattern, although *P. flesus* juveniles tended to concentrate in mesohaline areas rather than oligohaline areas.

The influence of the sediment on this species' abundance is not particularly obvious and may be indirect and related to prey availability (Gibson and Robb, 1992; Gibson, 1994; Amezcua and Nash, 2001). This was also reported for the Douro estuary and, indeed, the highest abundance of *P. flesus* was recorded in areas where prey abundance was high (Vinagre et al., 2005).

Bos (1999) studied habitat selection by juvenile flounder in the Elbe and concluded that abundance and biomass of 0-group *P. flesus* were positively correlated with water temperature in the observed range of 11 to 26 °C. The negative relationship obtained in the present study between *P. flesus* nursery areas and temperature reflects the fact that its distribution is limited to the north and central coast of Portugal, and not a preference for colder waters within estuaries.

For *S. solea*, results on its nursery characteristics differ considerably according to geographical area. Studies conducted in Northern Europe show that *S. solea* nursery areas may be located in marine coastal areas as well as within estuarine systems (Pihl, 1989; Dorel and Desaunay, 1991; Marchand, 1993; Rogers, 1994; Cabral and Costa, 1999). Estuarine nurseries are usually located in mesohaline areas (Dorel et al., 1991; Marchand, 1993; Cabral and Costa, 1999). According to Riley et al. (1981) and Marchand and Masson (1989) 0-group soles prefer salinities between 10 and 33‰. Other environmental factors that may be responsible for *S. solea* abundance within estuarine areas are sediment type and depth. Dorel et al. (1991) and Rogers (1992) attributed the patchy distribution of juveniles of this species within a nursery area to the sedimentary facies and Riley et al. (1981) reported *S. solea* preferences for sandy and muddy sediments. Cabral (2000b) suggested that in the Tejo estuary, 0-group *S. solea* may feed on intertidal mudflats that are located adjacent to their main nursery grounds and where dominant prey groups (polychaetes, amphipods and bivalves) are extremely abundant.

Knowledge on the ecology of *S. senegalensis* and *M. hispidus* is scarce and almost limited to studies conducted in the Portuguese coast. Cabral and Costa (1999) reported that, for the Tejo estuary, *S. senegalensis* juveniles concentrate in areas where benthic prey abundance is high. Cunha (1994) noticed a spatial segregation between juveniles and adults for *M. hispidus* in the Sado estuary, and reported that 0-group fish were concentrated in the same areas where *S. solea* and *S. senegalensis* juveniles presented high densities.

Our results show that some estuaries along the Portuguese coast have nursery grounds used by several flatfish species (e.g. Ria de Aveiro, Sado estuary), while in other systems a segregation is noticed, with the juveniles of different species in distinct estuarine areas (e.g. Minho and Mondego estuaries). This may indicate that the relevance of niche overlap, and even competition, may be extremely different according to estuarine system. Studies conducted in the Douro (Vinagre et al., 2005) and the Tejo (Cabral and Costa, 1999; Cabral, 2000b) estuaries have shown that niche overlap may be high. Similar results were obtained by Beyst et al. (1999), Darnaude et al. (2001) and Cabral et al. (2002) for coastal juvenile flatfish assemblages. However, a high niche overlap does not necessarily involve intra- or interspecific competition, since it may be considerably minimized by differences in resource use in other niche dimensions, such as time and space (Moore and Moore, 1976; Poxton et al., 1983; Burke, 1995) or by an extremely high abundance of resources as found by Vinagre et al. (2005). It is generally recognized that juvenile flatfish consume the most abundant food resources in a generalist and opportunistic manner (e.g. Lasiak and McLachlan, 1987; Beyst et al., 1999; Cabral, 2000b; Darnaude et al., 2001), which strongly reduces the potential for competition in highly productive systems such as estuarine habitats.

Peak densities of flatfishes recorded in nursery areas along the Portuguese coast were within the range of values reported for other geographical areas. For *P. flesus*, the highest density values reported in the literature are relative to the North Sea and the Baltic, where Berghahn (1984), Hinz (1989) and Kerstan (1991) registered maximum densities higher than 50 ind 1000 m^{-2}. For *S. solea*, the densities registered in Portuguese nurseries were usually higher than estimates obtained for estuaries and coastal areas around the United Kingdom (Symonds and Rogers, 1995) and within the range reported for the north coast of France (Dorel et al., 1991; Dorel and Desaunay, 1991).

The area effect on the estimated fish densities was not considered in the current analysis. High peak density values observed for *P. flesus* and *S. solea* in the Minho estuary might be explained by the effect of sampling in small and restricted areas of the estuary, without taking into consideration the extension of this nursery area or the existence of others. A more accurate evaluation of juvenile densities and their nursery areas will require a broader sampling strategy for the entire estuary comparing nursery areas with high densities with areas where juvenile fish are less abundant.

The available historical data on flatfish densities in Portuguese estuaries showed high inter-annual variability in abundance for *P. flesus*, *S. solea*, *S. senegalensis* and *M. hispidus* in two estuarine systems: the Tejo and the Sado estuaries. Except for *P. flesus*, which has decreased considerably in the Tejo estuary in recent years, no clear trend was found for the other species. The central Portuguese coast is considered the southern limit for the distribution of *P. flesus* and Cabral et al. (2001) attributed its decreased abundance to an increase in water temperature, caused by global climate change. This is consistent with previous findings of Von Westernhagen (1970) that *P. flesus* eggs are highly sensitive to water temperatures >12 °C (in winter), causing high levels of mortality.

The high variability in densities within nursery areas may be largely due to the inter-annual variation in recruitment. According to Rijnsdorp et al. (1992), recruitment is likely to be dominated by density-independent factors, such as water temperature, in the marine environment prior to or during the immigration to nursery areas. Marchand and Masson (1988, 1989) and Marchand (1993) suggested for *S. solea* that the timing of postlarval inshore migration depends on the hydrological regime and that hydrologically related aspects, such as hypoxia, can affect the nursery function of an estuary, reducing densities by emigration or even mass mortalities. It has also been demonstrated that density-dependent factors may have a high preponderance within nursery grounds, inducing high levels of juvenile mortality (Gibson, 1994; Rogers, 1994). These and other factors that affect or promote recruitment and settlement of flatfish in estuaries seem to have overall similar effects on these fish species densities since the same temporal patterns were found for the several species in the Tejo and Sado estuaries.

Estuarine nursery areas are also affected by human activities such as habitat reclamation, water quality impoverishment and fishing activities. The extent to which flatfishes depend on these estuarine grounds, as well as the contribution of these nursery areas to the maintenance of coastal stocks of commercially important species, is still poorly known. More knowledge on the relative contribution of each nursery area would be extremely useful in a management perspective to support strict protection measures to ensure flatfish resource sustainability.

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