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Small-scale distribution of *Solea solea* and *Solea senegalensis* juveniles in the Tagus estuary (Portugal)

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ABSTRACT

The distribution of *Solea solea* and *Solea senegalensis* in the Tagus estuary was studied following a small-scale approach. Preliminary sampling revealed that sole concentrated in two areas within their nursery grounds, the main subtidal channel and a large intertidal mudflat. Beam trawls were conducted intensively in the two areas in July 2006. Depth, salinity and water temperature were measured. Substrate samples were collected for sediment type determination and macrobenthos identification and quantification. Generalized linear models were applied in order to explain the occurrence and variability of soles' densities, using depth, salinity, water temperature and abundance of polychaetes, oligochaetes, amphipods, isopods and bivalves as explanatory variables. While *S. solea* was more abundant in the main subtidal channel, a deeper, warmer and lower salinity area, *S. senegalensis* abundance was highest at the intertidal mudflat area. Presence of both species in the two areas was associated with abundance of polychaetes (generally with another variable associated), and for *S. senegalensis* in the subtidal channel it was associated with amphipods and depth. Abundance of *S. solea* in the main subtidal channel was associated mainly with polychaetes abundance, while that of *S. senegalensis* was associated with amphipods density. In the intertidal mudflat, bivalves and polychaetes presented significant relationships with both species densities. Some of the factors that had been reported to be important for the distribution of these species in previous studies also do so at a finer scale; however, this small-scale approach provided an in-depth knowledge on habitat selection and spatial segregation of these species within this nursery area.

1. Introduction

The study of habitat use by fish has long been an important subject within fish ecology. Flatfish are among the most studied fish because of their high commercial value. A considerable amount of work has focused on identifying what determines the distribution of juvenile flatfish in nursery areas (e.g. Dorel et al., 1991; Rogers, 1992; Jager et al., 1993; Norcross et al., 1997; Amara et al., 2001; Le Pape et al., 2003; Nicolas et al., 2007), since it is believed that recruitment to the adult stock depends not only on the survival of the eggs and larvae but also on the survival and fitness of the juveniles that concentrate in these areas (Wiens, 1977; Houde, 1989; Beck et al., 2001). Nevertheless, most studies provide only a general picture of habitat use by juvenile fishes in nursery areas, due to the macro-scale sampling strategies employed. In order to better understand the habitat use patterns of fish within nursery areas, a small-scale approach is needed. Baltz et al. (1993) defined microhabitat as the site an individual fish occupies at a given point in time and concluded that careful measurements of many individuals associated with physical, chemical and biological variables should define the response of the population to environmental gradients. Research by Allen and Baltz (1997), Baltz et al. (1998) and Switzer et al. (2004) provided important insights into habitat use at a small-scale by flatfish juveniles in North American estuarine nursery areas. These studies presented crucial information for the understanding of the dynamics of those estuarine nurseries namely regarding species distribution within nursery areas and the variables driving habitat selection. This knowledge is lacking for European nursery areas. Given the importance of the Tagus estuary flatfish community (Cabral et al., 2007), it is of interest to study the habitat use patterns of the two most abundant flatfish species, *Solea solea* and *Solea senegalensis*, within its nursery grounds (Costa and Bruxelas, 1989; Cabral and Costa, 1999; Vinagre and Cabral, 2008; Vinagre et al., 2008). Several studies have produced important information on sole distribution at an estuarine scale throughout Europe, although the majority were conducted in areas where only *S. solea* exists. Most of these studies indicate that higher densities of juvenile sole occur in shallow areas with fine sediment (e.g.

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Koutsikopoulos et al., 1989; Dorel and Desaunay, 1991; Dorel et al., 1991; Rogers, 1992) and low salinity (e.g. Marchand and Masson, 1989; Marchand, 1991). Previous studies in the Tagus estuary have highlighted that juvenile *S. solea* and *S. senegalensis* concentrate in similar conditions to those found in other estuaries (Costa and Bruxelas, 1989; Cabral and Costa, 1999; Vinagre et al., 2006), yet all these studies were based upon macro-scale sampling strategies that did not cover all the habitats within the nursery area and failed to identify the areas of high concentration of these species juveniles on a fine-scale. In the Tagus estuary, juveniles of these species are the main target of beam trawl fisheries, occurring within the nursery areas (Baeta et al., 2005), which renders its management and in-depth knowledge on its habitat use patterns crucial for stocks' protection.

The aim of the present work was to (1) identify the main areas occupied by *Solea solea* and *Solea senegalensis* and (2) to identify the main variables driving their distribution within the estuarine nursery grounds where the two species occur together, using a small-scale approach.

2. Materials and methods

2.1. Study area

The Tagus estuary (Fig. 1), with an area of 325 km^2, is a partially mixed estuary with a tidal range of *ca*. 4 m. This estuarine system has a mean depth less than 10 m and about 40% of its area is intertidal fringed by extensive areas of salt marshes (Caçador et al., 1996). Although its bottom is composed of a heterogeneous assortment of substrates, its prevalent sediment is muddy sand in the upper and middle estuary and sand in the lower estuary and adjoining coastal area (Cabral and Costa, 1999). The mean river flow is 400 m^3 s^{-1}, though it is highly variable both seasonally and inter-annually. Salinity varies from 0, 50-km upstream, to *ca*. 35 at the mouth of the estuary (Cabral et al., 2001). Water temperature ranges from 8 °C to 26 °C (Cabral et al., 2001).

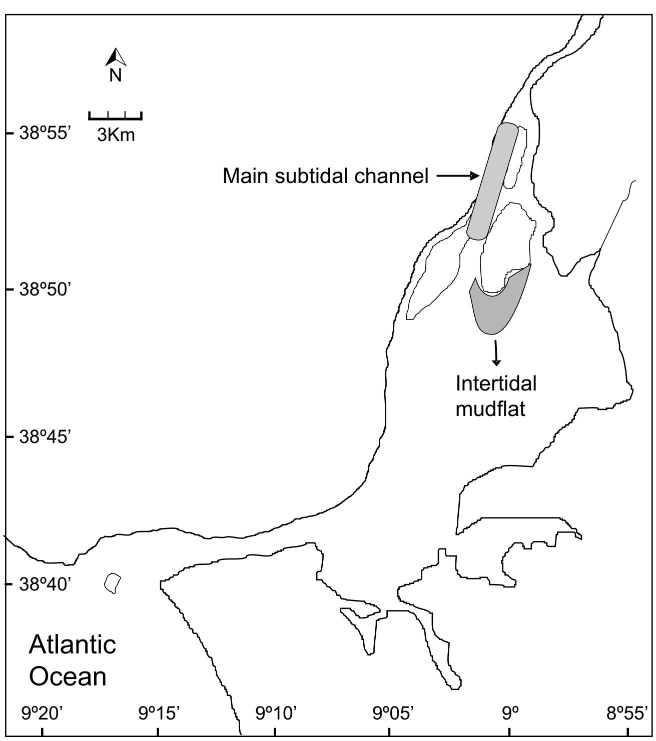

Fig. 1. Location of the main subtidal channel and of the intertidal mudflat area in the Tagus estuary study area.

Two important nurseries for sole have been identified in the Tagus estuary in previous studies by Costa and Bruxelas (1989) and Cabral and Costa (1999), yet only in one of the nursery grounds do the two soles occur together (*Solea solea* only occurs in the uppermost nursery area, near Vila Franca de Xira), and is thus the focus of this study. This nursery has a mean depth of 4.4 m, and has low and highly variable salinity and a high proportion of fine sand in the substrate (Cabral and Costa, 1999). *Solea solea* 0-group juveniles are known to colonise this nursery around May leaving the estuary towards the coast in October–November (Cabral and Costa, 1999). *Solea senegalensis* colonise the upper Tagus later, yet in July high abundance of both species can be found at this nursery (Cabral and Costa, 1999).

2.2. Sampling

Beam trawls were conducted in this nursery in July 2006 in order to capture *Solea solea* and *Solea senegalensis*. Preliminary sampling, random by habitat type, was carried out in all the channels and around the estuarine islands of the nursery in order to determine where soles were concentrated. It was concluded that both species concentrated in two areas, the main subtidal channel and a broad intertidal mudflat (Fig. 1). This approach was useful since it allowed us to concentrate the sampling effort in the areas where soles concentrate. An intensive sampling program was implemented in these two areas in order to study the distribution of soles in a small-scale. A total of 84 hauls were conducted randomly within both these areas (58 hauls in the main channel and 26 in the intertidal mudflat area). A minimum distance of 10 m was kept between trawls during each sampling session, in order to prevent running over areas already disturbed by the fishing gear. The average area swept by each trawl was 1088 m^{-2}. We estimate that density of trawls was 23.77 trawls 1000 m^{-2} in the main channel and 16.25 trawls 1000 m^{-2} in the mudflat, over the whole sampling period. Trawls were conducted with a 2-m beam trawl with 5-mm stretched mesh at the cod end. The length of the average tow was 544 m. All soles caught were identified. Although these species are very similar, they can be easily distinguished in the field through close inspection of the pectoral fin of the ocular side, which presents different coloration. The distance travelled in each tow was determined based on a global positioning system device (GPS) and the headline length was used as a measure of width in the swept area calculations. Fish abundance was expressed as density (number of individuals per 1000 m^2). Mean density and standard deviation per area were calculated. Depth, temperature and salinity were measured at the beginning of each trawl. At the beginning of each trawl, and at every 100 m, a sediment sample was taken with a van Veen grab, for macrobenthic organisms' collection. Another sediment sample was taken for sediment type assessment. Sediments were transported to the laboratory and then sieved through a 0.5-mm nylon mesh to collect specimens. Organisms were preserved in 4% buffered formalin and identified at a later date. Polychaetes, amphipods, isopods, bivalves and oligochaetes' densities were selected as variables for analyses since they were composed mainly of *S. solea* and *S. senegalensis* prey. Sediment samples were dried at 60 °C and a 100 g subsample was wet-sieved through a 0.063-mm mesh sieve and dried. The remaining sediment was sieved through a four-sieve column. Weight of the residue remaining in each sieve was then expressed as a percentage of the total subsample weight and the <0.063-mm fraction calculated from the difference between the initial subsample weight and the sum of the other fractions. The following categories of grain size were considered: mud (<0.063 mm), fine