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Recruitment of flatfish species to an estuarine nursery habitat (Lima estuary, NW Iberian Peninsula)

Sandra Ramos [a,*], Pedro Ré [b], Adriano A. Bordalo [a,c]

[a] *Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR); Rua dos Bragas 289, 4050-123 Porto, Portugal*
[b] *Faculdade de Ciências da Universidade de Lisboa, Laboratório Marítimo da Guia, Estrada do Guincho, 2750-374 Cascais, Portugal*
[c] *Laboratory of Hydrobiology, Institute of Biomedical Sciences, University of Porto, Largo Professor Abel Salazar, no. 2, 4099-003 Porto, Portugal*

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ABSTRACT

One of the present concerns of fish biologists involves defining and identifying nursery habitats in the context of conservation and resource management strategies. Fish nursery studies usually report upon nursery occupation during the latter juvenile stages, despite the fact that recruitment to nurseries can start early in life, during the larval phase. Here we investigated the use of a temperate estuarine nursery area, the Lima estuary (NW Portugal), by initial development stages of flatfish species before and after metamorphosis, integrating the larval and juvenile phases. The Lima estuarine flatfish community comprised twelve taxa, seven of which were present as pelagic larvae, six as juveniles and three as adults. There was a general trend of increasing spring–summer abundance of both larvae and juveniles, followed by a sharp winter decrease, mainly of larval flatfishes. The Lima estuary was used by *Solea senegalensis*, *Platichthys flesus* and *Solea solea* as a nursery area, with direct settlement for the two first species. In contrast, indirect settlement was suggested for *S. solea*, with metamorphosis occurring outside the estuarine area. Estuarine recruitment of *S. senegalensis* varied between years, with young larvae occurring in the estuary throughout a prolonged period that lasted 6–9 months, corroborating the protracted spawning season. *P. flesus*, the second most abundant species, exhibited a typical spring estuarine recruitment, without inter-annual variations. Developed larvae arrived in the estuary during spring, whereas the 0-group juveniles emerged in the following summer period. The present study contributes new insight to our understanding of the economically important *S. senegalensis*, and highlights the importance of integrating the planktonic larval phase into traditional flatfish nursery studies.

1. Introduction

Many species of marine fishes employ a life-history strategy in which the larvae take up a pelagic lifestyle and the adults are closely associated with the benthos. Perhaps no group of fishes has committed to this strategy so completely as flatfishes, whose morphological transformation from a symmetrical pelagic larva to the ultimate bottom mimic is an unparalleled feat of ontogeny (Fuiman, 1997). Metamorphosis, characterized by severe morphological (e.g. eye migration and a 90° rotation in posture), anatomical and physiological transformations, enables the transition from a pelagic to a benthic lifestyle (Able and Fahay, 1998). This transition is usually denominated at settlement. Some flatfish species colonize their nursery areas early in life, during the pelagic larval phase, employing a direct settlement strategy (Gibson, 1973). In contrast, when nursery recruitment occurs after settlement, during the juvenile phase, it is considered indirect settlement. Recruitment success depends on survival and growth of recruits, both through the highly variable larval stages and during the juvenile phase spent in the nursery grounds (Van der Veer, 1986; Beverton, 1995; Andersen et al., 2005). Thus, the settlement of planktonic larvae on a suitable nursery habitat is one of the most important features of flatfish population dynamics. In fact, migrations of metamorphosing larvae to the proper nursery habitats have been recognized as an important control of recruitment strength (Bell et al., 2001; Warlen et al., 2002; Garcia et al., 2003). For species that spawn offshore but are dependent upon inshore nurseries, larvae that enter the estuary on flood tide but fail to settle during some critical period of time may be subsequently flushed back into coastal waters, where they are presumably lost to the population (Amara et al., 2000; Curran and Able, 2002; Cabral, 2003). Thus, the dynamics of nursery areas play a major role in determining overall population size and, hence, their study contributes towards understanding recruitment variability (Rijnsdorp et al. 1995; Iles and Beverton, 2000; Van der Veer et al., 2000; Walsh et al., 2004).

Nursery areas may be described as a restricted area where juveniles of a species spend a limited period of their life cycle, during which they are spatially and temporally separated from the adults and

* Corresponding author. Tel.: +351 222062285; fax: +351 222062284.
E-mail address: ssramos@icbas.up.pt (S. Ramos).

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where their survival is enhanced through optimal conditions for feeding, growth, and/or predation refuge (Bergman et al., 1988; Pihl et al., 2002). Since survival may also be optimized in other adjacent habitats, recent frameworks defend that a habitat only functions as a nursery when it is able to yield relatively more adult recruits per unit of area than other juvenile habitats used by a species (Beck et al., 2001; Cattrijsse and Hampel, 2006). However, this definition can be limited, because it can omit habitats that have a small per unit area contribution to adult recruitment, but may be essential for sustaining adult populations (Dahlgren et al., 2006). Thus, the traditional nursery concept that defines nurseries simply as habitats supporting high juvenile densities should not be abandoned and still retains values in the context of discussing conservation and restoration strategies.

Flatfishes are usually abundant within estuarine and coastal fish assemblages (Yamashita et al., 2001; Bailey et al., 2003; Le Pape et al., 2003). Along the northeast Atlantic and Mediterranean margins, several flatfish species use estuarine and coastal areas as nursery habitats (Henderson and Seaby, 1994; Nash and Santos, 1998; Watts and Johnson, 2004; Vinagre et al., 2005). The coastal zones of the North Sea and the Wadden Sea have been extensively studied, since those areas comprise important nursery areas for several flatfish species of commercial interest, namely *Pleuronectes platessa*, *Limanda limanda*, *Platichthys flesus* and *Solea solea*. Within the Iberian Peninsula, the NE Bay of Biscay has been identified as an important nursery area for *S. solea* (Amara and Paul, 2003; Le Pape et al., 2003; Desaunay et al., 2006; Gilliers et al., 2006). Some southern Iberian estuaries are also used as nursery grounds for *S. solea* and *S. senegalensis* (e.g. Costa and Bruxelas, 1989; Drake and Arias, 1991; Andrade, 1992; Cabral, 2000b; Cabral et al., 2002; Drake et al., 2002). The Minho and Douro estuaries, located along the northern coast of Portugal, have recently been recognized as nursery areas for *P. flesus* and *S. solea* (Cabral et al., 2007; França et al., 2009; Freitas et al.,), but based solely upon the estuarine juvenile phase. In fact, a common feature of most fish nursery studies is to deal with only one particular phase of ontogenetic development, typically the latter stages of nursery occupation. Thus, the majority of flatfish nursery studies tend to focus only on the benthic juvenile phase (e.g. Hostens, 2000; Power et al., 2000; Gilliers et al., 2004), indirectly inferring information about larval stages (Vinagre et al., 2007; Vinagre et al., 2008) due to the lack of empirical data. Accordingly, further studies are required in order to incorporate early larval stages into flatfish nursery studies, thereby combining the pelagic larval and benthic juvenile stages into a more comprehensive assessment of the importance of nurseries to different phases of the life cycle of each species of interest. For example, a recent study of the Lima estuarine flatfish community emphasized the concept that environmental control varies throughout ontogenetic development, stressing the importance of integrating all the early life of a species in flatfish nursery studies (Ramos et al., 2009).

The present study forms part of a comprehensive analysis of the use of an estuarine nursery by early life stages of flatfishes, including both the larval and juvenile stages. Presently, it is known that several flatfish, namely *S. senegalensis*, *S. solea and P. flesus*, utilize the Lima estuary as planktonic larvae (Ramos et al., 2006b) and also among the benthic community (Ramos et al., 2009). Apart from the economic importance of these species, several biological and ecological aspects of their early life history are still unknown, namely their mechanisms of nursery recruitment and the specific habitats that they use (Vinagre et al., 2008; Freitas et al., 2009). Thus, our aim was to investigate the estuarine recruitment of flatfishes to the Lima estuary, through the temporal and spatial patterns of larval and juvenile abundances over a 2-year period.

2. Material and methods

2.1. Study area

The Lima River is an international water body with headwaters in northwestern Spain, that flows westward through Portugal and drains into the Atlantic Ocean at 41° 40′ N and 8° 50′ W in the vicinity of the 32 000 inhabitant city of Viana do Castelo, northern Portugal (Fig. 1). Its watershed covers 2446 km^2 of which 47% is located in Portuguese territory. The temperate Lima River has a small open estuary, with a semidiurnal and mesotidal regime (3.7 m), with an average flushing rate of 0.40 m s^{-1}, a river flow of 70 m^3 s^{-1}, and a hydraulic residence time of 9 days. The Lima estuary is a partially mixed system, exhibiting seasonal vertical stratification of salinity during the winter period, during which salinity sharply increases with depth. A layer of fresh water is sometimes present at the surface, associated with periods during which river discharges increase. Temperature is vertically stratified, with cooler water typically found near the bottom of the water column, except during wintertime thermal inversions (Ramos et al., 2006a). Due to the geomorphology of the system, the lower estuary is highly urbanized and composed of a narrow channel dredged to a depth of 10 m, and with hardened shorelines. The river mouth is partially obstructed by a 2 km long jetty that deflects the river flow to the south (Fig. 1). The middle estuary is a shallow

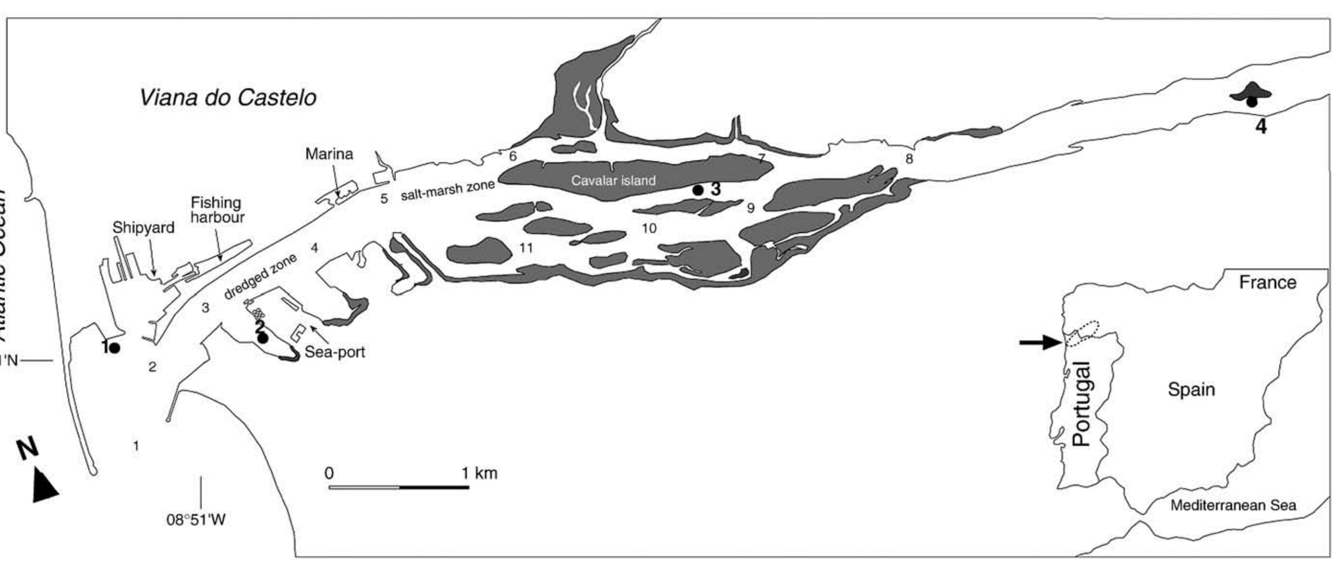

Fig. 1. Lima River estuary and location of the sampling stations where larval (small numbers 1–11) and juvenile flatfishes (numbers in bold 1–4) were collected. Shaded area represents sand islands and saltmarshes.