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Immigration and early life stages recruitment of the European flounder (*Platichthys flesus*) to an estuarine nursery: The influence of environmental factors

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ABSTRACT

Connectivity between coastal spawning grounds and estuarine nurseries is a critical step in the life cycle of many fish species. Larval immigration and transport-associated physical–biological processes are determinants of recruitment success to nursery areas. The recruitment of the European flounder, *Platichthys flesus*, to estuarine nurseries located at the southern edge of the species distribution range, has been usually investigated during its juvenile stages, while estuarine recruitment during the earlier planktonic life stage remains largely unstudied. The present study investigated the patterns of flounder larval recruitment and the influence of environmental factors on the immigration of the early life stages to the Lima estuary (NW Portugal), integrating data on fish larvae and post-settlement individuals (<50 mm length), collected over 7 years. Late-stage larvae arrived at the estuary between February and July and peak abundances were observed in April. Post-settlement individuals (<50 mm) occurred later between April and October, whereas newly-settled ones (<20 mm) were found only in May and June. Variables associated with the spawning, survival and growth of larvae in the ocean (sea surface temperature, chlorophyll *a* and inland hydrological variables) were the major drivers of flounder occurrence in the estuarine nursery. Although the adjacent coastal area is characterized by a current system with strong seasonality and mesoscale variability, we did not identify any influence of variables related with physical processes (currents and upwelling) on the occurrence of early life stages in the estuary. A wider knowledge on the influence of the coastal circulation variability and its associated effects upon ocean-estuarine connectivity is required to improve our understanding of the population dynamics of marine spawning fish that use estuarine nurseries.

1. Introduction

Estuaries function as temporary habitats for early life stages of many fishes, a critical period in the life cycle of marine fishes (Elliott et al., 2007; Potter et al., 2015). Although the passage of early life stages through estuarine environments can present a 'bottleneck' on the abundance of adult populations, there is still a poor understanding of these events (Able and Fahay, 2010). The connectivity between spawning areas and nurseries is one of the major determinants of the dynamics of fish populations (Cowen and Sponaugle, 2009). Processes such as pelagic larval dispersal and supply depend on the biophysical regulators of offspring production and availability, as well as on the interactions between local/regional hydrodynamics, larval delivery into estuaries, and the behavioural capabilities of the individual larvae (Cowen and Sponaugle, 2009; Sale et al., 2010; Potter et al., 2015). During the dispersal stage, eggs and larvae experience high mortality, which strongly influences recruitment variability (Houde, 2008). Furthermore, population connectivity depends on additional processes, since effective transfer requires successful recruitment to the juvenile receiving population (Sale et al., 2010). For example, the availability of suitable settlement and nursery habitat, or the processes that affect the transition from larvae into benthic juveniles, such as larval condition and benthic predation, will influence recruitment (Cowen and Sponaugle, 2009).

The European flounder, *Platichthys flesus* (Linnaeus, 1758), is a widely-distributed flatfish along the northeastern Atlantic coast and widely regarded as having an estuarine resident or semi-catadromous life stage (Elliott et al., 2007). This species reproduces in winter/early spring in marine waters (Campos et al., 1994; Dando et al., 2011; Grioche et al., 1997; Koubbi et al., 2006) and migrates during the early life stages to nursery grounds (e.g. Bos, 1999; Jager, 2001; Martinho et al., 2008; Summers, 1979). Little is known about *P. flesus* settlement patterns (Jager, 2001; Bos and Thiel, 2006; van der Veer et al., 1991) and its favoured settlement habitat (estuary vs. coastal areas) (Daverat et al., 2012). In general, for flatfishes, it has been emphasized

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that the processes affecting recruitment variability are more relevant during the pelagic phase, although post-settlement processes seem to regulate juvenile abundance (Bolle et al., 2009; Geffen et al., 2007; van der Veer et al., 2000). However, and although *P. flesus* has been described to enter estuaries during the larval phase (Bos, 1999; Jager, 1998; Ramos et al., 2010), most studies concerning estuarine nurseries for this species are mainly focused on post-settlement juveniles (Amara et al., 2009; Cabral et al., 2007; Freitas et al., 2009; Jager, 2001; Martinho et al., 2008; Vasconcelos et al., 2010). Consequently, the supply of *P. flesus* early-life stages to estuaries, and associated environmental constraints on recruitment variability, have been investigated mainly in juveniles. These studies show that the abundance of juvenile flounder in estuaries may be related to the average seawater temperature of the previous year (Henderson and Seaby, 1994; Vinagre et al., 2009) and with river runoff, precipitation, and wind prior to estuarine colonization (Martinho et al., 2009). Once in the estuary, environmental constraints vary between larval and juvenile phases, with *P. flesus* larvae showing a strong seasonal structure mainly regulated by biological features such as the spawning season (timing and duration), while juveniles are markedly controlled by site-specific characteristics such as sediment structure, distance from the river mouth, and salinity regime (Ramos et al., 2009a). Therefore, any natural or anthropogenic events that affect either the quality of the nursery areas, the delivery of young to those areas, or the passage of the young from the nursery areas, will affect success of the recruitment to the adult population.

Given the demonstrated effects that the pre-settlement processes may have upon year-class strength, it is important to investigate the connectivity between ocean and estuaries and the processes associated with the supply of the pelagic larvae to the primary nursery grounds (Cowen and Sponaugle, 2009). The Lima estuary, located in the North-Western (NW) Iberian Peninsula, has been identified as a nursery habitat for European flounder (Ramos et al., 2010) and because the NW Iberian Peninsula represents the southern edge of its geographical range, environmental processes become particularly relevant, as the species becomes more vulnerable to environmental fluctuations at its distributional edges (Miller et al., 1991). Therefore, this study aimed to (i) document the patterns of the recruitment of European flounder to the Lima estuary, using pelagic-larval and post-settlement juvenile flounder data describing 7 years within a 12-year period, and (ii) investigate the associated environmental factors, following the hypothesis that estuarine recruitment at the larval phase is influenced by the physical and biological processes of ocean and estuarine dynamics.

2. Material and methods

2.1. Study area

The Lima estuary (Portuguese NW Atlantic coast of the Iberian Peninsula) has a catchment of 2446 km^2 (Fig. 1) and a discharge regime with an annual average flow of 70 $m^3\ s^{-1}$ mainly controlled by two hydroelectric power stations located upstream. The tidal regime, the main hydrodynamic forcing action of the estuary (Falcão et al., 2013), is mesotidal and semidiurnal with a range of 3.7 m during spring tides and an upstream influence that reaches 20 km. The Lima estuary can be divided into the following three areas with distinct geomorphological features: the lower estuary (0–3 km from the mouth) is a narrow, deep and navigational channel with artificial banks; the middle estuary (3–7 km) is a broad shallow zone with salt marshes and tidal sandy islands; and the upper estuary (7–20 km) is a shallow and narrow channel with small sandy islands (Ramos et al., 2010). Despite seasonal hydrological fluctuations in the Lima estuary (Ramos et al., 2006a),

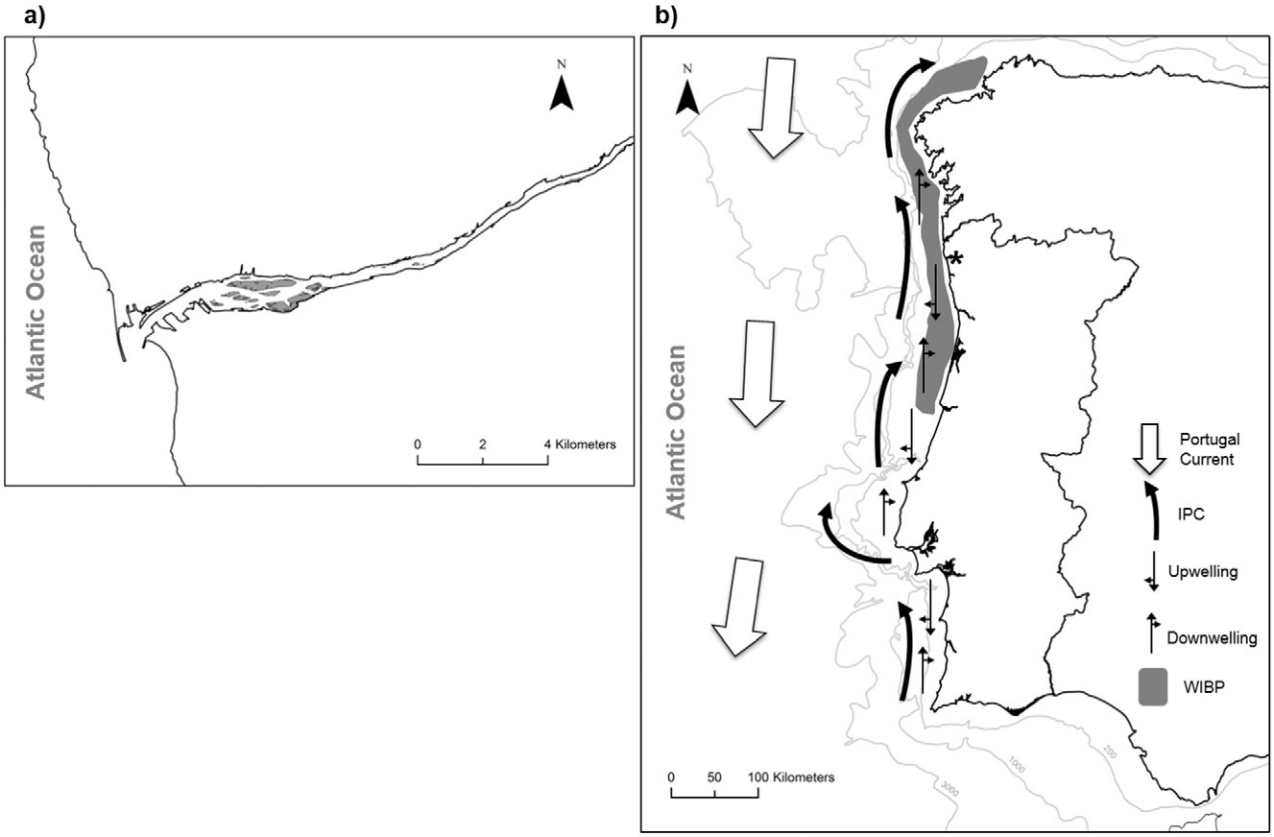

Fig. 1. Location of the Lima estuary in the NW Iberian Peninsula (Portugal): a) Lima estuary (41.68° N; 8.84° W); b) Western Iberian Peninsula, with the main oceanographic features represented (adapted from Queiroga et al., 2007 and Peliz et al., 2005). The isobaths of 200 m, 1000 m and 3000 m are presented in grey. ✱ represents the location of the Lima estuary.