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Habitat loss and gain: Influence on habitat attractiveness for estuarine fish communities

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A B S T R A C T

Habitat structure and complexity influence the structuring and functioning of fish communities. Habitat changes are one of the main pressures affecting estuarine systems worldwide, yet the degree and rate of change and its impact on fish communities is still poorly understood. In order to quantify historical modifications in habitat structure, an ecohydrological classification system using physiotopes, i.e. units with homogenous abiotic characteristics, was developed for the lower Lima estuary (NW Portugal). Field data, aerial imagery, historical maps and interpolation methods were used to map input variables, including bathymetry, substratum (hard/soft), sediment composition, hydrodynamics (current velocity) and vegetation coverage. Physiotopes were then mapped for the years of 1933 and 2013 and the areas lost and gained over the 80 years were quantified. The implications of changes for the benthic and demersal fish communities using the lower estuary were estimated using the attractiveness to those communities of each physiotope, while considering the main estuarine habitat functions for fish, namely spawning, nursery, feeding and refuge areas and migratory routes. The lower estuary was highly affected due to urbanisation and development and, following a port/harbour expansion, its boundary moved seaward causing an increase in total area. Modifications led to the loss of most of its sandy and saltmarsh intertidal physiotopes, which were replaced by deeper subtidal physiotopes. The most attractive physiotopes for fish (defined as the way in which they supported the fish ecological features) decreased in area while less attractive ones increased, producing an overall lower attractiveness of the studied area in 2013 compared to 1933. The implications of habitat alterations for the fish using the estuary include potential changes in the nursery carrying capacity and the functioning of the fish community. The study also highlighted the poor knowledge of the impacts of habitat changes on fish due to coastal development and urbanisation and emphasises that ecosystem management and conservation will benefit from a wider understanding of habitat functional roles and habitat changes influencing the functioning and structure of the fish communities.

1. Introduction

Habitat destruction has been taking place on a large scale over the past 300 years in many estuaries and coastal areas (Elliott and Cutts, 2004; Lotze et al., 2006) and it is recognised as one of the major threats to biodiversity, structure and functioning of marine ecosystems (Airoldi et al., 2008; Halpern et al., 2008; Wolanski and Elliott, 2015). In addition to supporting cities and harbours having a large economic and social importance (Airoldi and Beck, 2007), estuaries also have great ecological value and are among the most biologically productive and valuable habitats in temperate aquatic areas (Costanza et al., 1997). However, increasing human activity over recent centuries has increased the vulnerability of estuarine and coastal marine ecosystems to habitat degradation and loss (Lotze et al., 2006) and affected several critical ecosystem services (Barbier et al., 2011).

The modification of shorelines and the introduction of large amounts of physical materials and man-made structures adversely

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changes the functioning of the system. This is regarded as permanent habitat loss or change, given that it requires large-scale engineering works to be reversed; similarly it is a form of pollution under the definition of materials added to the natural system which result in harm to the biology of the system or to human welfare (Wolanski and Elliott, 2015). The impact of land claim in estuarine areas (i.e. the anthropogenic removal of estuarine area, such as wetlands, for space for urban or agricultural use; older literature use the term reclamation but it is argued her that an area is being claimed from the sea rather than re-claimed from it), causing habitat loss, has been greater than the effects of any polluting discharges (McLusky and Elliott, 2004). Major impacts to wetlands, including saltmarshes, seagrasses and soft-sediment habitats, have been caused by coastal development (e.g. construction of marinas, the widening and dredging of channels for navigation, tourist developments and infrastructures, aquaculture, etc.), and defence (e.g. breakwaters, seawalls, jetties, dykes) (Airoldi and Beck, 2007; Elliott et al., 2016; Wolanski and Elliott, 2015).

Estuaries are important as essential fish habitats providing nursery grounds, migration corridors, refuge and feeding areas for many species, as well as supporting their own resident fish community (Able and Fahay, 2010; Elliott and Hemingway, 2002; Potter et al., 2015). These functions are closely related to the physical and ecological structure of the estuary, which comprises a complex mixture of distinctive habitat types (Pihl et al., 2002). Alterations to estuarine habitats, or to the hydrophysical linkages between them, are likely to compromise the ability of fish larvae or young juveniles to reach favourable nursery habitats, which can have negative population effects, such as reduced recruitment success or near complete failure of a year class (Peterson, 2003). Additionally, the loss of structurally complex habitats, such as seagrasses and marshes, often leads to lower abundances and declines in species richness (Airoldi et al., 2008). Morphological pressures (i.e. changes to the shape, size and physical complexity of the areas such as seagrass habitat loss, bathymetric changes) have also had a main role in affecting potential habitat productivity in transitional waters through effects on biomass of resident and marine migrant fish (Franco et al., 2009a; Zucchetta et al., 2016).

Despite these evident changes, there is still limited knowledge and understanding of the magnitude and importance of habitat losses in coastal systems (Airoldi et al., 2008). The historical losses of soft-bottom habitats are poorly known (Airoldi and Beck, 2007), as well as the impacts of engineering structures on coastal habitats and their communities, such as how they change or introduce new ecosystem functions and services (Bulleri and Chapman, 2010; Dugan et al., 2011; Elliott et al., 2016; Perkins et al., 2015). Knowledge of the extent of changes is especially relevant given the fact that the implementation of conservation and management goals for the marine and estuarine ecosystems requires identifying baselines acting as reference conditions (Borja et al., 2012). Yet, this is often limited by the lack of historical data prior to large-scale human impacts and by the lack of information on the drivers of change (Airoldi and Beck, 2007; Bianchi et al., 2014; Claudet and Fraschetti, 2010). Without long-term data series, change has been assessed by alternative means, such as anecdotal knowledge (Al-Abdulrazzak et al., 2012; Alleway and Connell, 2015; Katikiro, 2014) or expert opinion (Halpern et al., 2008).

Given the need to further understand the drivers and the level of habitat change, to help ecosystem management and conservation and restoration efforts, the present study aimed to test the hypothesis that historical habitat changes have the potential to affect the overall attractiveness of estuarine habitats for fish communities. To achieve this, the study quantified: i) the changes in habitat structure of an estuarine area over a period of 80 years, and ii) the attractiveness of each habitat and overall estuarine area for fish communities and potential implications of the changes observed.

2. Material and methods

2.1. Methodological approach

The historical changes to an estuarine area were studied by applying an ecohydrological classification system in order to produce ecologically meaningful habitat maps for fish communities. The habitats created by this approach are units of homogenous physical characteristics that are referred to as physiotopes, after Bouma et al. (2005). The classification system was based on a hierarchical integration of variable-layers, allowing for an increasingly detailed level of description of habitat (Bouma et al., 2005; Stevens et al., 2008). The classification system was used to compare the habitat structure of the estuarine area between past (1933) and present (2013) scenarios, and estimate the area lost or gained for each physiotope. Due to the lack of historical data on fish communities using the estuary, and to further understand the potential implications of the changes observed on those fish communities, the attractiveness of the lower estuary to fish communities in both years (1933 and 2013) was estimated using a qualitative method, based on available information from literature review and expert judgment. This method scored each physiotope considering the main estuarine habitat functions for estuarine representative fish species, and its relative cover area. Finally, the physiotopes were clustered according to their attractiveness (see Fig. 1).

2.2. Study area

The Lima estuary (NW Portugal) is a small North Atlantic temperate system (approximately 20 km length) (Fig. 2) draining an international river basin. The tidal regime is mesotidal (average range of 3.7 m) and semidiurnal, with an annual average freshwater flow of 70 $m^3\ s^{-1}$, regulated upstream by two hydroelectric dams. The estuary has three distinct morphological areas: 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). Historically, the middle and upstream areas have retained most of their natural banks (being part of the EU Natura network), while the lower estuary has been subject to extensive modification within the last century, with the building of walled banks, a large shipyard, a fishing harbour, a commercial seaport, two marinas and two jetties protecting the river mouth. Aerial photographs of the estuary comparing the past with the present situation have shown that the major modifications in the Lima estuary have occurred in the lower part. Additionally, given that more detailed historical information was available for this area (because it is the most urbanised), the ecohydrological classification system was applied to the lower estuary only (Fig. 2).

2.3. Ecohydrological classification system

The ecohydrological classification system used the following variables based on their importance to benthic and demersal fish communities: depth, substratum type, hydrodynamics (namely, water velocity) and vegetation cover. As the lower estuary covers from the mouth to 3 km upstream, salinity was considered to be homogeneous within a euhaline area. The variables and their threshold values selected were adapted from Bouma et al. (2005) and Stevens et al. (2008). Different methodologies (see below)