Ecological Indicators 67 (2016) 743–752

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Fish communities' response to implementation of restoring measures in a highly artificialized estuary

Nuno Castro[a,*], Pedro M. Félix[a], João M. Neto[b], Henrique Cabral[c,d], João Carlos Marques[b], Maria José Costa[c], José Lino Costa[c,d]

[a] MARE – Marine and Environmental Sciences Centre, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal
[b] MARE – Marine and Environmental Sciences Centre, Departamento de Ciências da Vida, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, 3004-517 Coimbra, Portugal
[c] MARE – Marine and Environmental Sciences Centre, Departamento de Biologia Animal, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal
[d] Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

ARTICLE INFO

Article history:
Received 23 December 2015
Received in revised form 14 March 2016
Accepted 17 March 2016
Available online 25 April 2016

Keywords:
Hydromorphological modifications
Mitigation measures
Ichthyofauna
Community structure and function
Mondego estuary
Portugal

ABSTRACT

Over the years, the Mondego estuary has undergone various anthropogenic impacts. One of the most serious was the closing of the communication between the two arms of the system (north and south), in the 1990s, which promoted eutrophication and a consequent water quality decline in the south arm. Several mitigation measures were subsequently implemented, in particular the re-establishing of the communication between the two arms in 2006, increasing water flow and reducing water residence time in the south arm. The present study aimed to evaluate the impact of management measures on the ecological and conservation condition of the Mondego estuary, through a longitudinal assessment of the structure and composition of the fish communities over a decade. The Mondego fish community showed important modifications over the years, in terms of structure, ecological quality and conservation value. The fish community status improved following the reconnection of both arms. In the south arm those changes appear to be more evident than in the other estuarine areas, where an inverse pattern was observed in the last few years. A redistribution of the fish species within the system may have been responsible for those unexpected alterations in the north arm and upstream area.

1. Introduction

Estuaries, located between terrestrial, freshwater and marine environments, are considered to be among the most important aquatic ecosystems (Elliott and Whitfield, 2011), with major ecological and socio-economic relevance (Sheaves et al., 2014), due to its intrinsic characteristics, diversity of habitats and high productivity (McLusky and Elliott, 2004). These transitional waters are, in fact, very attractive sites for the establishment of important biological communities, offering suitable nursery and spawning areas, presenting shelter from predators, providing abundant food resources and being an integral part of migration routes (Beck et al., 2001; Costa et al., 2001; Vasconcelos et al., 2011). As a result, over the years estuaries have been preferred sites for human settlement leading to the implementation of agriculture and industrial developments, fishing and also recreational activities (Vasconcelos et al., 2007). A long history of exploitation and resulting activities have affected these systems (Aubry and Elliott, 2006), mainly through habitat reclamation and modification (Kennish, 2002,), contamination (França et al., 2005; Caçador et al., 2012), overfishing (Costa et al., 2001; Jackson et al., 2001) and introduction of invasive species (Chaínho et al., 2015). These impacts are, consequently, mirrored in the ecological water quality and biological communities (McLusky and Elliott, 2004).

The Mondego estuary is a small, warm-temperate, mesotidal system located on the western coast of Portugal (40°08′N; 8°50′W) (Marques et al., 2003). With an area of 8.6 km^2 and 21 km in length, it flows through the Lower Mondego Valley surrounded by 150 km^2 of high valued agriculture land (Fig. 1) (Neto et al., 2008). At the river mouth the watercourse bifurcates into two arms, encircling the Murraceira Island. The north arm reaches depths of 5–10 m at high tide whilst the south arm is limited to 2–4 m. This south arm is composed of approximately 75% intertidal mudflats while in the north arm are found less than 10% of this type of areas. The tidal range is different in both arms, being 2–3 m in the north and 1–3 m in the south. This difference is mainly due to the largely silted

* Corresponding author. Tel.: +351 217500148x20328; fax: +351 217500009.
E-mail address: ngcastro@fc.ul.pt (N. Castro).

http://dx.doi.org/10.1016/j.ecolind.2016.03.040
1470-160X/

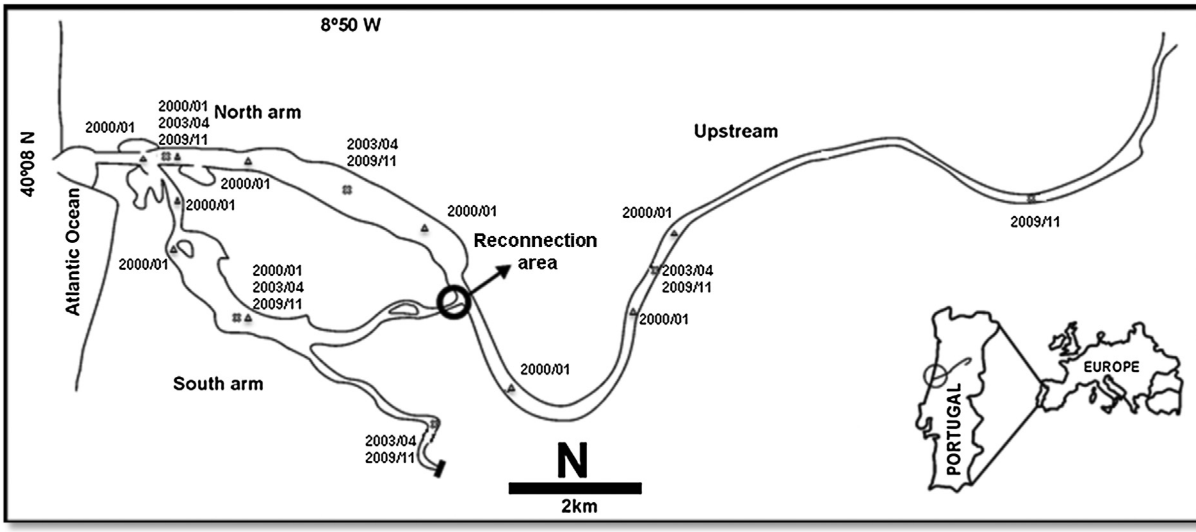

Fig. 1. Map of the study area, showing the sampling locations of the fish community for the three time periods considered in this study. The reconnection area between the two arms of the system and the different estuarine areas (south arm, north arm and upstream area) are also indicated.

upstream areas of the south arm which causes differences in water flow. The mean water flow in the estuary is 79 $m^3 s^{-1}$ but it can vary considerably and reach above 140 $m^3 s^{-1}$ in rainy years and drop to 27 $m^3 s^{-1}$ in dry years (Marques et al., 1993; Flindt et al., 1997; Neto et al., 2008).

The downstream areas of the south arm support *Spartina maritima* marshes and *Zostera noltei* (seagrass) meadows but in its upstream areas the seagrass community disappeared and blooms of the opportunistic macroalgae *Ulva* spp. occurred frequently during the 1990s (Dolbeth et al., 2014). In the north arm these seagrass ecosystems were never present. Benthic communities are dominated by opportunistic species, mainly bivalves and polychaetes in higher salinity areas, and amphipods and oligochaetes in upstream areas (Chaínho et al., 2006). An average of 40 fish species use frequently the estuary (Jorge et al., 2002; Leitão et al., 2007; Martinho et al., 2007; Baptista et al., 2010). In spring and summer time, juveniles of some species occur in the upper estuary (oligahaline areas), but in the rest of the year, they tend to disperse through the middle and lower estuarine areas. *Dicentrarchus labrax*, *Pomastochistus microps*, *Pomatoschistus minutus*, *Solea solea*, *Platichtys flesus* and *Diplodus vulgaris* are amongst the most abundant species (Leitão et al., 2007).

The estuary has a high economic value as it supports numerous industries, including salt-works, aquacultures, mercantile and fishing harbors as well as agricultural exploitation areas, which cause numerous physical impacts and nutrient discharges in the area (Marques et al., 2007a). The north arm accommodates most of the maritime traffic and is often dredged (Marques et al., 1993).

The Mondego estuary has suffered several anthropogenic pressures over the years and can be regarded as a model of long human exploitation. These pressures have resulted in hydromorphological modifications and in consequent ecological decline (Marques et al., 2003, 2007a; Patrício and Marques, 2006; Teixeira et al., 2008; Neto et al., 2010). In an attempt to reverse this situation, a strategy involving several mitigation measures was firstly designed in 1997/98, culminating in a more intense action in 2006 (Marques et al., 2007a; Veríssimo et al., 2012). For several decades, multiple anthropogenic stressors (e.g. eutrophication, dredging, and physical modifications) led to several changes in the Mondego estuary (see Neto et al., 2010 for more details). The most severe was the eutrophication that occurred in the south arm during the early 1990s. This led to a decline in water quality, due to upstream communication closure between the two arms induced by several physical modifications undertaken in the estuary (Marques et al., 1993, 2007a,b; Lopes et al., 2000; Martins et al., 2005, 2007; Verdelhos et al., 2005; Patrício and Marques, 2006; Cardoso et al., 2008, 2010; Martinho et al., 2008; Patrício et al., 2009; Teixeira et al., 2009; Dolbeth et al., 2011). The obstruction resulted in increased water resilience time and nutrient concentration, promoting macroalgae blooms (*Ulva* sp.) and a regression in the seagrass coverage (*Z. noltei*; 15 ha in 1986 to 0.02 ha in 1997) in this part of the estuary (Patrício and Marques, 2006; Marques et al., 2007a; Martins et al., 2007; Neto et al., 2013). Some mitigation measures were implemented during the late 1990s to reverse this situation. The goals were to improve the water quality, reduce the nutrient load and water residence time in the south arm. Two major measures were applied: (i) reduction of freshwater inflow from the Pranto River into the south arm, by diverting it upstream to the north arm by a sluice; and (ii) improvement of the water flow by a partial re-establishment (~1 m wide) of the upstream connection between the south and north arms for limited periods (1.5–2 h before and after the tidal peak) (Lillebø et al., 2005). After this intervention, the system showed signs of improvement, the seagrass beds partially recovered and the macroalgae blooms were no longer detected (Marques et al., 2007a; Patrício et al., 2009; Cardoso et al., 2010; Dolbeth et al., 2011). Due to those improvements after the implementation of the first measures, the Portuguese Environmental Agency adopted a second, larger scale, intervention plan for the system. Therefore, in 2006 the reestablishment of communication between both arms was made permanent aiming to increase the water flow and reduce water resilience time in the south arm (Marques et al., 2007a; Neto et al., 2010; Veríssimo et al., 2012).

The expectation was that following these management measures of the late 1990s and 2006 the biological communities of the Mondego estuary and especially those located in the south arm would recover. The objective of this study was to evaluate the impact of the management measures on the ecological and conservation condition of the Mondego estuary, through a longitudinal assessment of the composition and structure of their fish assemblages over a decade using several indices reflecting different aspects of the community. This methodology can be extended to other studies aiming to assess impacts of anthropogenic activities on estuarine fish communities, including artificialization or renaturalization of this type of systems.