Changes in the fish assemblages of a coastal lagoon subjected to gradual salinity increases

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ABSTRACT

This study analyses fish data to understand how the gradual increase of salinity registered in a coastal lagoon and consequently, anthropogenic disturbance, affected the fish communities. For that, fish assemblages of the Ria de Aveiro were sampled monthly in 3 years from different decades (1988, 1997 and 2012). Dominant species were *Atherina boyeri*, *A. presbyter*, *Sardina pilchardus*, *Dicentrarchus labrax*, *Liza aurata* and *L. ramada*. Significant differences in fish communities were detected among years in both terms of density and biomass. Results pointed out to a taxonomic and functional homogenization of fish assemblages in 2012, when salinity was higher and its range of variation across the whole lagoon more uniform. Marine species were clearly associated with 2012, while some freshwater species only appeared in 1988, reflecting the gradual salinity increase in the lagoon. Overall, both the structure and function of fish assemblages of Ria de Aveiro have changed over the time, which was attributed to human activities to maintain the lagoon operational.

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1. Introduction

Coastal lagoons are inland water bodies that connect to the ocean, at least intermittently, by one or more restricted inlets, and whose water depth seldom exceeds a few meters (Kjerfve, 1994). They are among the most productive aquatic ecosystems due to high levels of primary production, organic matter and habitat diversity, offering optimal niches for numerous aquatic species (Villanueva et al., 2006) and providing several ecosystem services essential to mankind (Dolbeth et al., 2016). As such, their surrounding areas are usually densely populated, subjecting lagoons to several anthropogenic pressures (Dolbeth et al., 2016; Lopes et al., 2013).

A lagoon might or might not be subject to tidal mixing, and salinity can vary from that of a coastal fresh-water lake to a hypersaline lagoon, depending on the geomorphology, climate and the consequent hydrologic balance (Kjerfve, 1994). A coastal lagoon naturally exists in a state of dynamic equilibrium with its environmental drivers, in particular, climate, hydrodynamics,

topography, sediment supply and sea level history (Duck and da Silva, 2012; Jewell et al., 2012; Newton et al., 2014). From a geological evolution perspective, a lagoon is essentially an ephemeral system, whose inlets have a tendency for sediment accretion (Duck and da Silva, 2012). In fact, several coastal lagoons nowadays are maintained artificially, directly through engineering interventions or indirectly due to activities within their catchment areas (Duck and da Silva, 2012). These sort of activities may have several impacts on the lagoon's aquatic communities, both due to direct effects (e.g. dredging, changing sediment dynamics, Lillebø et al. (2015)) or indirect effects (e.g. salinity incursion, Pérez-Ruzafa et al. (2005) and Tuchkovenko et al. (2015)). As a result, changes in the lagoon's biological communities have been reported, from changes in the structure and functioning of the communities e.g. plant, invertebrate and fish communities, Pérez-Ruzafa et al. (2006), Lillebø et al. (2015), imbalanced populations due to appearance of invasive species (Pérez-Ruzafa et al., 2005), among other effects.

Ria de Aveiro is a complex coastal lagoon in the western Portugal that comprises a wide range of biotopes (e.g. wetlands, salt marshes and mudflats) used as nursery areas for many valuable species, including fish, crustaceans and bivalves (Lillebø et al., 2015; Lopes et al., 2007; Rodrigues et al., 2011). Regarding fish, previous

investigations comparing the fish assemblages of Ria de Aveiro during the past century (*i.e.* 1912, 1915, 1981, 1988, 1997, 1999, 2000) showed some changes in species presence: a total of 13 species have recently disappeared (e.g. *Barbus bocagei, Lipophrys pholis, Gaidropsarus vulgaris*), while 29 species have occurred only since 1981 (e.g. *Diplodus vulgaris, Pegusa lascaris, Symphodus melops*) (Pombo et al., 2002). On the other hand, these authors concluded that in terms of presence of ecotrophic guilds (using classifications by Elliott and Dewailly (1995), the lagoon maintained a similar structure during the whole period (no significant differences with time), i.e. a dominance of estuarine residents and marine adventitious species, which fed mostly on invertebrates and fishes, with oviparous reproduction (with either pelagic or benthic eggs) (Pombo et al., 2002).

However, we still do not know how the fish community has changed towards the current and progressive trends of higher salinity intrusion in the lagoon. The initiating causes of the increase in the Ria de Aveiro's water salinity thought the time were dredging operations, together with the deterioration of abandoned saltpans existing in the lagoon (Lopes et al., 2013; Picado et al., 2009). Both events induced to important tidal modifications that also promoted the deepening of the lagoon main channels (Lopes et al., 2013; Picado et al., 2009). This deepening led to a generalized increase in the extension of lagoon-flooded area (Lopes et al., 2013) and the progressive rise in the tidal amplitude has affected the lagoon, increasing water velocity and with water becoming more saline in the Ria de Aveiro through time (da Silva et al., 2004). As such, the aim of this paper was to analyse how this gradual increase of salinity registered in the lagoon, and consequently the human activities disturbance, might be affecting the fish communities. For that, this paper studies the changes in the fish community structure and function of the Ria de Aveiro (and their linkages with environmental variables) in 3 years from distinct decades: 1988, 1997 and 2012.

2. Materials and methods

2.1. Study area

The Ria de Aveiro is a shallow coastal lagoon, with a maximum width of 45 km long and 10 km wide, located on the Northwest Atlantic coast of Portugal (40″ 38′ N, 8″ 44′ W) (Fig. 1). The lagoon has four main branches spreading from the lagoon mouth: Mira, Ílhavo, Espinheiro and São Jacinto channels. The average depth of the Ria de Aveiro is around 1 m, and the greatest depths (about 30 m) are in the lagoon entrance (Araújo et al., 2008) near the harbour facilities. The whole area of the Ria de Aveiro and its natural capital supports several social-economic activities, from agriculture, tourism and other activities intrinsically associated with major towns in coastal areas: fishing, aquaculture, harbour port facilities, industries and salt-production (Dolbeth et al., 2016; Lillebø et al., 2015; Lopes et al., 2007). However, these human related activities have only re-settled after the creation of an artificial inlet in 1808, in response to persistent accretion of the natural inlet (Lillebø et al., 2015; Lopes et al., 2013). In 1936, works started to maintain the channel network wide and deep enough to permit safe navigation to support harbour and port activities, including the construction of training walls and breakwaters, together with extensive dredging (Duck and da Silva, 2012). These activities continue to this day and have transformed Ria Aveiro in to a tidal-dominant system (Duck and da Silva, 2012). Thus, nowadays, the hydrology in the lagoon is fundamentally dominated by tidal forcing, which led to a strong mixture of the water masses (Freitas et al., 2014). Regarding the vertical gradients, in particular of
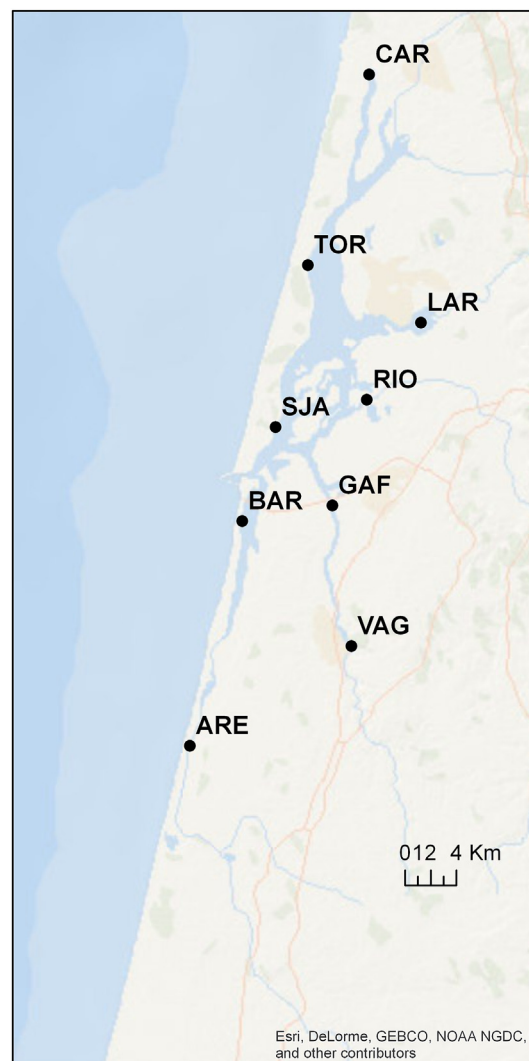
Fig. 1. Map of the Ria de Aveiro coastal lagoon, with indication of sampling sites: BAR= Costa Nova, GAF = Gafanha de Nazaré, SJA = São Jacinto, ARE = Gafanha do Areão, VAG= Vagos, CAR= Carregal, RIO = Rio Novo do Príncipe, LAR = Largo do Laranjo, TOR = Torreira.

temperature and salinity, they are minimal in comparison with the longitudinal gradients (Dias et al., 1999). For summer conditions, the areas close to the lagoon mouth generally presented high salinity and low temperature (almost characteristic of ocean waters), whereas in the upstream areas salinity decreased and temperature increase (Dias et al., 1999). A similar trend in the salinity variation along the lagoon' gradients is maintain in general throughout the whole year, except for a slight decrease in the upstream sites during winter months (unpublished data). However, the spatial distribution of salinity within the lagoon has changed since the artificial inlet was constructed in 1808, as a result of the increase in tidal prism (da Silva et al., 2004). At the beginning of twentie[th] century, the transition zone (which ranged from salinities of 5–30) characterized the whole lagoon, while the marine zone (with salinities >30) extended inland until a maximum of 4 Km from the lagoon mouth (da Silva et al., 2004). In the 1960s, marine waters penetrated the major channels up to 15 Km from the sea, and in 2000 even further inland, reducing the area of the transition zone (da Silva et al., 2004).