Marine Pollution Bulletin 111 (2016) 221–230

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Effect of historical contamination in the fish community structure of a recovering temperate coastal lagoon

Eva García-Seoane [a,⁎,1], João Pedro Coelho [b,c], Cláudia Mieiro [b,d], Marina Dolbeth [a,d], Tiago Ereira [b], José Eduardo Rebelo [a], Eduarda Pereira [b]

[a] Department of Biology, University of Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal
[b] CESAM & Department of Chemistry, University of Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal
[c] Interdisciplinary Centre of Marine and Environmental Research (CIIMAR), University of Porto, Rua das Bragas, 289, 4050-123 Porto, Portugal
[d] Centre for Functional Ecology, Department of Life Sciences, University of Coimbra, Apartado 3046, 3001-401 Coimbra, Portugal

ARTICLE INFO

Article history:
Received 27 November 2015
Received in revised form 29 June 2016
Accepted 3 July 2016
Available online 8 August 2016

Keywords:
Coastal lagoon
Fish assemblage
Ria de Aveiro
Trace metals

ABSTRACT

This study aimed to assess the impact of trace element concentrations in fish assemblages of a recovering coastal lagoon. Fish, water and sediment were sampled in winter and summer in the Ria de Aveiro (Portugal). Multivariate analyses were used to examine the relationship between fish assemblages and environmental variables (physical-chemical parameters, contaminants and sediment grain size). In winter, fish density and biomass were mainly affected by the water turbidity, while Li concentration in the water column was found to be significant for fish biomass. During summer, a significant relationship was found between fish density and temperature, Hg, Li and Zn concentration in the sediment. These contaminants were mainly associated with the historically contaminated area, were *Liza* spp. and *Dicentrarchus labrax* appeared as dominant species. Environmental variables were not significant for fish biomass. The historical contamination in the Ria de Aveiro still seems to exert some influence on fish community structure.

1. Introduction

Transitional areas, such as estuaries and coastal lagoons, are complex systems comprising a natural gradient of physical-chemical characteristics from river to sea without distinct boundaries. These systems undergo permanently variable conditions due to tide hydrodynamics, diverse sediment geomorphology and fluctuating abiotic parameters (e.g. dissolved oxygen and salinity) (Wołowicz et al., 2007). Nevertheless, transitional areas are among the most productive ecosystems, supporting aquaculture, salt-production, fishing activities, port facilities and industries (Dolbeth et al., 2010; Lillebø et al., 2015; Lopes et al., 2008). Regarding fish communities, these areas are important nursery and feeding habitats as well as part of migration routes for several fish species, supporting the offshore stocks of economically valuable species (Dolbeth et al., 2010; Martinho et al., 2013).

Owing to transitional areas high value regarding services provided, they are among the most threatened areas, enduring the impacts of multiple anthropogenic stressors, such as eutrophication (Dolbeth et al., 2011), habitat loss (Kennish, 2002) and chemical contamination (Gravato et al., 2010). Among these stressors, contamination has been recognized as contributing significantly as disturbance sources in estuaries and coastal lagoons, since most contaminants will be deposited in sediments, which act as both sink and source of chemicals, increasing their bioavailability to the aquatic biota (Hill et al., 2013). The acknowledgement of the environmental risks through estuarine contamination has resulted in increasing number of research focusing on abiotic quality criteria and establishing biomarkers of responses in order to accurately evaluate the risks to the aquatic biota (Abukila, 2015; Gonçalves et al., 2013; Gravato et al., 2010; Morelli and Gasparon, 2014).

The presence, abundance and distribution of fish communities depends on their capacity to respond to a variety of physical and chemical factors to which they are exposed (Dyer et al., 2000). The ichthyofauna composition in estuaries is usually dynamic, reflecting changes in environmental factors and life history patterns of the various species (Whitfield and Elliott, 2002). As such, fish communities have often been used to illustrate changes in the condition of estuarine environments, in particular as they relate to contamination of these systems (Whitfield and Elliott, 2002). The direct and indirect coupling between fish communities and human impacts on estuaries reinforces the choice of this taxonomic group as a biological indicator (Pérez-Domínguez et al., 2012; Whitfield and Elliott, 2002). Many fishes are suitable as early-warning signals of human-induced stress on natural ecosystem dynamics, or conversely, as indicators of ecosystem recovery and

⁎ Corresponding author.
E-mail address: evagseoane@gmail.com (E. García-Seoane).
[1] Present address: Instituto Português do Mar e Atmosfera (IPMA), Av. Brasília, s/n, 1449-006 Lisboa, Portugal.

http://dx.doi.org/10.1016/j.marpolbul.2016.07.005
0025-326X/

resilience (Holmlund and Hammer, 1999; Mieiro et al., 2010; Mieiro et al., 2014).

High levels of metals discharged in aquatic ecosystems may result in selective removal of sensitive life stages of vulnerable fish species, whereas persistent exposure to sub-lethal levels causes reduced growth and condition, among others (Bervoets et al., 2005). Thus, it can be expected that metal contamination will also result in alterations of the fish community (Bervoets et al., 2005). Depending on the tolerances of ichthyofauna, both fish abundance and species diversity can provide managers with a good indication of the 'stress' of the system (Whitfield and Elliott, 2002).

The Ria de Aveiro is a coastal lagoon located in the north western coast of Portugal. In past years, sewage and effluent discharges from various industries have contributed as point sources of metal contamination to almost all areas of the lagoon (Pacheco et al., 2005). The industrial effluents were the main cause for high levels of metal contamination in sediments and water column, and the most relevant point of entry was the Esteiro de Estarreja, which connects to the Laranjo Basin (Monterroso et al., 2007; Pereira et al., 2009). Nowadays, it is considered historical contamination, restricted to 2-km^2 area in Laranjo Basin (Lillebø et al., 2015; Pereira et al., 2009). However, long-term monitoring of the system highlighted persistent risks, despite an overall improvement in local contamination levels, given that metal transport processes were enhanced by hydrological changes and may have increased environmental pressure away from the contamination source (Coelho et al., 2014). Studies in the Ria de Aveiro have focused almost exclusively on mercury (Hg) contamination, reflecting the emission history of a chlor-alkali plant (Pereira et al., 2009). However, Monterroso et al. (2007) found high levels of iron (Fe), manganese (Mn), cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn) mainly retained in the deep layers of sediments at the Laranjo basin. The same authors also stressed that the surface sediments showed low metal extractability, which indicates low availability to the surrounding biota. Metal mobilization and its transport may occur throughout the lagoon, following sediment disturbance events (e.g. dredging, floods, among others), which may originate sporadic toxicity far from the main polluting source (Coelho et al., 2014). Therefore, it becomes crucial to evaluate the presence of these contaminants along the Ria de Aveiro and their potential impact on biological communities, despite the ongoing recovery of the system.

In the Ria de Aveiro, several authors have assessed Hg contamination in fishes at cellular, biochemical and individual level (Abreu et al., 2000; Guilherme et al., 2008; Mieiro et al., 2014; Mieiro et al., 2011b). The effect of Hg was also studied on biological communities, such as macrobenthos (Nunes et al., 2008) and zooplankton (Cardoso et al., 2013). Nevertheless, to our knowledge, the overall metal contamination and potential impacts for the fish community structure have never been evaluated for Ria de Aveiro or other coastal lagoon system. Hence, the objective of this study was to assess the chemical concentrations present in a typical coastal lagoon in the southern Europe and their impact for fish assemblages. This knowledge is valuable to understand the effects of anthropogenic impacts on lagoon ecosystem and thus, relevant to the coastal lagoons management.

2. Materials and methods

2.1. Study area

The Ria de Aveiro is a shallow coastal lagoon with a complex morphology. Many branching channels (of which the four main are the Ovar, Murtosa, Ilhavo, and Mira channels) are connected to the ocean by a single tidal outlet, via an intervening tidal lagoon (da Silva et al., 2004; Lillebø et al., 2015). The lagoon has a maximum width and length of 10 and 45 km, respectively, and covers an area of 66–83 km^2 during a spring tide. The minimum tidal range is 0.6 m (neap tides), and the maximum tidal range is about 3.2 m (spring tides), corresponding to a maximum and a minimum water level of 3.5 and 0.3 m, respectively (Dias et al., 2000). Biologically, it is considered rich in nutrients and organic matter and is, therefore, a highly productive environment, providing a habitat for several commercially important fish and invertebrate species (Araújo et al., 2008).

2.2. Sampling strategy

Sampling consisted of two campaigns, one conducted in winter (February 2012) and the other in summer (August 2012). The sampling sites (Fig. 1) were located: *i)* within the first 2–3 km of each main channel entrance (BAR, GAF, SJA), where water residence times are generally lower than 2 days (Dias et al., 2001); *ii)* at the edges of the main channels (ARE, CAR, VAG), with water residence times of over 14 days (Dias et al., 2001); *iii)* approximately in the middle of the longest channel (TOR) (approximately 7 days water residence time); *iv)* in the main freshwater area (RIO); *v)* in the area that historically showed the highest levels of metal pollution (LAR). Previous studies report that each main channel can be considered as an independent estuary, with almost no particle mixing between them, which excludes secondary pollution from other areas of the system (Dias et al., 2001). Due to bad weather and technical constraints, the sampling was not conducted during winter in CAR. Samples were taken at low tide and during daylight hours. Fish sampling consisted of 3 successive hauls at the same location using a beach seine net, with a final mesh size of 10 mm. The area enclosed by the net was approximately 1550 m^2 at all stations except at VAG, were it was 500 m^2 due to its narrow topographic configuration. After sampling, fish were taken to the laboratory, where they were frozen (−20 °C) for preservation.

At each sampling station, water physico-chemical parameters such as temperature, salinity, dissolved oxygen and pH (WTW Cond. 330i/set - Tetracon® 325 probe; WTW, model Oxi 330i/SET and WTW pH 330i/set - SenTix® 41 probe) were also measured. Only surface measurements were taken because previous studies point that the Ria the Aveiro should be considered as vertically homogeneous (Dias et al., 1999; Moreira et al., 1993; Rebelo, 1992).

At each site, 5 replicate sediment samples were obtained from the top 5 cm layer, and stored in plastic bags and kept cool until arrival at the laboratory. Subsurface water samples were also collected from the adjacent water channel in acid-washed poly(ethylene terephthalate) (PET) bottles and kept on ice during transportation to the laboratory.

2.3. Laboratory methodologies

2.3.1. Sediment analysis

At the laboratory, macrodetritus were removed from the sediment and samples were then oven-dried to constant weight at 50 °C, homogenized and sieved through a 2 mm sieve before storage until analysis. Grain size analysis was performed gravimetrically, on a series of sieves, whose fractions were weighted: silt and clay (<63 μm), very fine sand (63–150 μm), fine sand (150–250 μm), medium sand (250–500 μm), coarse sand (500–1000 μm), very coarse sand and gravel (>1000 μm). These were converted in ϕ scale ($-\log_2$ mm) and median grain size determined by GRADISTAT Version 8.0 (Blott and Pye, 2001), using logarithmic Folk and Ward method, with the % of the different sediment fractions.

Total mercury in sediments (limit of quantification LOQ – 0.01 μg kg^{-1}) was determined by Atomic Absorption Spectroscopy (AAS) after thermal decomposition and gold amalgamation, using a LECO 254 Advanced Mercury Analyser (AMA) (for more details please see Costley et al. (2000)). The accuracy and precision of the methodology was checked on a daily basis (in the beginning and at the end of the day) through the replicate analysis of Certified Reference Material (CRM), namely Mess-3. The relative standard deviation between replicates was always lower than 9% ($n > 3$), with a recovery efficiency ranging from 99 to 109% ($n = 22$).