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The importance of habitat-type for defining the reference conditions and the ecological quality status based on benthic invertebrates: The Ria Formosa coastal lagoon (Southern Portugal) case study

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ABSTRACT

Coastal lagoons are complex systems, with considerable habitat heterogeneity and often subject to high temporal dynamics, which constitutes a great challenge for ecological assessment programs. For defining reference conditions for benthic invertebrates, under the EU Water Framework Directive objectives, historical data from the Ria Formosa leaky lagoon (wet surface area of about 105 km^2) located in Southern Portugal was used. The influence of habitat features, such as channel depth, sediment type and seagrass cover, on the expression of these biological communities, was inferred by analyzing subtidal data collected at stations with different environmental characteristics. Such heterogeneity effect was analyzed at the community compositional and structural levels, and also for three indices in the multimetric Benthic Assessment Tool (BAT). This tool for the assessment of ecological status includes the Margalef index, Shannon–Wiener diversity index, and AZTI's Marine Biotic Index (AMBI). Significant variations associated with environmental features were reflected on specific reference conditions at four habitats in the lagoon. After habitat calibration, the Benthic Assessment Tool (BAT) revealed that, in general and for the period of time covered by this historical data set, the status of the lagoon corresponded to a good ecological condition, which is mainly due to its high water renewal rate. Such classification is in accordance with the majority of studies at the lagoon. However, at punctual sites with human induced high water residence times, significantly lower BAT values were registered. Such community degradation can be associated with physical stress due to salinity increase and to a degradation of water quality, with occurrence of occasional dystrophic crisis, triggered by low water renewal. Habitat differentiation was a crucial step for a correct evaluation of the ecological condition of invertebrate communities across the lagoonal system.

1. Introduction

Coastal lagoons are "inland water systems connected to the ocean by one or more restricted inlets that remain open at least intermittently, and have water depths which seldom exceed a few meters" (Kjerfve, 1994). These shallow water systems have been classified as transitional waters (TW) by most of the European countries, especially in the Mediterranean basin and in some Baltic countries (McLusky and Elliott, 2007). However, other countries classified them as coastal waters (CW), namely Portugal (Bettencourt et al., 2004). Coastal lagoons may be regarded as singular water bodies within the Water Framework Directive (WFD) goals, since they usually do not present a clear salinity gradient and frequently are not substantially influenced by freshwater. Tagliapietra and Ghirardini (2006) preferred to use the term 'transitional environments' or 'transitional habitats' and Pérez-Ruzafa et al. (2010) denominated coastal lagoons as "transitional ecosystems" between transitional and coastal waters. The location of coastal lagoons between land and sea subjects them to strong anthropogenic pressures due to tourism and/or heavy shellfish/fish farming (Aliaume et al., 2007). Diffuse pollution is an additional threat, mainly through agricultural and/or industrial effluents and domestic sewages drainage from their catchment areas (Aliaume et al., 2007).

Under the WFD implementation, several problems and constrains arose associated to the natural large environmental variability of aquatic systems. As explained above, the categorization of some water systems as TW or CW is sometimes dubious and difficult, particularly for coastal lagoons. Before ecological quality status (EQS) assessment, the water systems must have been classified not only into different categories, such as TW or CW, but also their typology and the different water bodies within each

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system must have been previously defined (Vincent et al., 2002). For the division of TW and shallow CW into relatively homogenous water bodies, Ferreira et al. (2006) proposed a methodology based on three aspects: salinity and morphology as natural component; a normalized pressure index and an eutrophication symptoms classification. Within these waterbodies there is however a mosaic of habitats (Gamito, 2008) and, while in the end the ecological status must be reported at the water body level (Vincent et al., 2002), reference conditions to determine that EQS need to be defined accounting for the type of habitat features that will influence biological communities (de Paz et al., 2008; Muxika et al., 2007; Teixeira et al., 2008a). Therefore, if within a water body different habitats are to be monitored, then reference conditions that reflect the expected natural biological communities at each habitat should be defined (Teixeira et al., 2008a).

By the imposition of the WFD, the ecological EQS of the main water bodies has to be defined. Several methodologies have been proposed for the different ecological components, and for benthic invertebrates one of the methodologies is the Benthic Assessment Tool (BAT) (Teixeira et al., 2009), a multivariate metric based on the Margalef (1958), the Shannon–Wiener diversity (Shannon and Weaver, 1963) and AMBI (AZTI Marine Biotic Index, Borja et al., 2000) indices. The results of the application of this tool were comparable to the results of the application of other multimetric indices adopted by different European countries, and therefore the methodology was approved in the last intercalibration exercise (Carletti and Heiskanen, 2009). BAT was adopted by Portugal to assess the ecological quality of coastal and transitional waters using macroinvertebrate communities.

The Ria Formosa is a mesotidal leaky lagoon, located in Southern Portugal. The lagoon has five sand barrier inlands and six inlets. The tidal amplitude ranges from 3.6 m on spring tides to 1.0 m on neap tides, which causes important semidiurnal and fortnightly tidal amplitude variations. The lagoon geomorphology and the tidal amplitude allow important diurnal water exchanges with the ocean. Consequently, the water residence time is short, with an estimated average time of 1.5 days (Saraiva et al., 2007). However, upstream locations present higher residence times due to irregular tidal flushing throughout the lagoon (Tett et al., 2003). In these locations, residence time can reach an average of 2.4 days (Mudge et al., 2008). The salinity in the main tidal channels varies between 32 and 36.5 throughout the year (Newton and Mudge, 2003), with occasional lower values due to run-off episodes, and higher values at the inner locations due to intense evaporation and lower water renewal rates. The lagoon has a wet area of approximately 105 km^2, which comprises the tidal channels with seagrass beds (26.7 km^2), extensive intertidal areas with salt marshes (35.7 km^2), intertidal bare sediments (28.5 km^2), salt-pans (11.5 km^2) and fish farms (2.6 km^2) (Meireles, 2004). The seagrasses *Zostera noltii*, *Zostera marina*, and *Cymodocea nodosa*, dominate the intertidal mudflats and the shallow subtidal (Cunha and Santos, 2009; Cunha et al., 2009). The Ria Formosa, with this large wet area, together with the sand-barrier islands and the back terrestrial lands, covering a total area of 184 km^2, constitutes a National Park since 1987. The park is also a Ramsar site since 1980, and an important bird area, which denotes its environmental importance.

Over the last decades, the resident population around the lagoon and its hydrographic basin has increased by almost 60%, from 100 thousand inhabitants in 1970 to 160 thousand in 2001 (Rodrigues, 2004). Every summer, the population increases significantly due to tourism. Consequently, the anthropogenic pressures on the system have increased, mostly in the vicinity of the main cities. High levels of bacteria, nutrients, metals and organochlorine compounds were detected in several areas of the Ria Formosa, mainly in the surroundings of the main cities (Bebianno, 1995). The benthic invertebrate composition also reflected the degraded environment

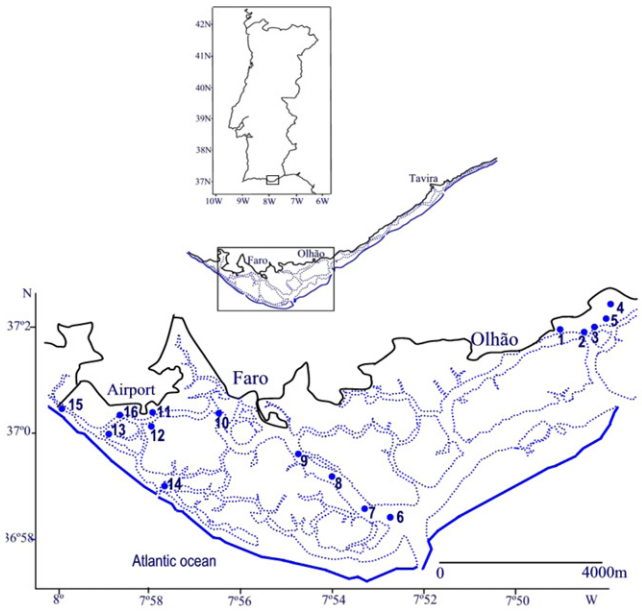

Fig. 1. Ria Formosa and approximate location of subtidal sampling stations: 1–5 (Gamito, 2006); 6–14 (Calvário, 1995); 15 and 16 (Project RECITAL INAG).

near the main cities (Austen et al., 1989). Recently, Redondo-Gómez et al. (2009) reported the presence of high concentrations of heavy metals near the vicinity of Faro airport, although in other areas of Ria Formosa the concentration of metals in the water column is low (Caetano et al., 2007).

Five waterbodies have been identified in the Ria Formosa coastal lagoon (Ferreira et al., 2006) resulting essentially from the morphology and drainage system patterns of the dendritic tidal channels; and also from the variation of chlorophyll *a* and dissolved oxygen concentrations, acting as indicators of state of nitrogen and phosphorus pressure. According to these authors, one of the waterbodies, located in the eastern side of Ria Formosa presented a lower water quality. Three of these water bodies, located in the center and in the western side of the lagoon, were covered by the present study.

During the last decades of the 20th century, several researchers carried out extensive sampling of benthic invertebrates in the Ria Formosa (Gamito, 2008 and references therein). The objective of this study was to use the historical data gathered to: (a) define significantly distinct habitats within the lagoon from a WFD assessment perspective; (b) establish habitat-specific reference conditions for the subtidal soft-bottom macroinvertebrate communities; and, finally, (c) test the behaviour of a WFD compliant multimetric method, the BAT, using an additional dataset, including data on relevant pressures in the lagoon, such as a decrease on water renewal, to validate the method.

2. Methods

The data analyzed and discussed in detail in Gamito (2008) was used to select two datasets (Table 1): one dataset including reference sites (RC) to establish habitat specific reference conditions; and a validation dataset (VS), including both impacted and undisturbed sites, to test the adequacy of uni and multiparametric indices to assess the ecological quality status of the Ria Formosa (Fig. 1 and Table 1). Two additional sites, sampled in 2006, were added to the VS dataset. Only subtidal soft-bottom stations were considered, namely among those sampled by Gamito (2006) and Calvário (1995). The criteria used in stations selection for each dataset are explained in Section 2.2.