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Determining useful benchmarks for the bioassessment of highly disturbed areas based on diatoms

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ABSTRACT

Modern ecological assessments of running waters are based on the *a priori* definition of ecological benchmarks, given by reference-quality sites. Such benchmarks are established at the level of ecoregions, typologies, or site. Yet, in highly disturbed regions, such as coastal areas of European countries, the assessment of streams' water quality based on the reference condition concept is very difficult, due to the lack of undisturbed sites. Among others, the reduced number of reference sites may have as a consequence the definition of imprecise ecological benchmarks. Here we tested the hypotheses that (1) the increase in the number of potential reference sites (2) the definition of more precise abiotic thresholds using the least disturbed condition approach (LDC), and (3) the use of diatom assemblages, as the most ubiquitous element in lowland areas, would result in refinement and eventual sub-division of existing river types of a highly disturbed area, such as the Portuguese centre-western region. For this purpose, abiotic data characterising natural conditions of 55 sites from a littoral highly disturbed region were used in a hierarchical classification analysis that revealed the existence of three different sub-groups. In addition, a three-step approach was used to define thresholds for the pressure variables in LDC. Based on these new thresholds, sites in LDC were selected. A hierarchical classification performed to the LDC diatom spring assemblages revealed the existence of two sub-groups, concordant with two of the abiotic sub-groups. Several species contributed to the dissimilarity between the two sub-groups (*e.g.*, *Achnanthidium minutissimum* and *Karayevia oblongella*). Differences between the sub-groups were also found in the trait proportions of stalked species. New benchmark values for these two sub-groups, based on the scores of the official diatom index, the Indice de Polluosensibilité Spécifique (IPS), were different from the previous reference value used. Yet, no biological benchmark values were established for one of the groups due to the absence of sites in the LDC. Our study suggests that streambed substrate is an important characterisation variable in the river type definition and highlights that, in spite of the potential refinement in reference conditions and typology obtained, an alternative approach that does not require the use of reference sites should be explored in the future.

Introduction

Modern ecological assessments of streams and rivers are frequently based on the *a priori* definition of ecological benchmarks, given by reference-quality sites, to which assessed sites are matched in terms of assemblage composition and structure (Hawkins et al., 2010). Such ecological benchmarks have been established at the level of ecoregions, typologies or site-specific (Hawkins et al., 2010).

In Europe, and according to the Water Framework Directive (WFD; European Commission, 2000), type-specific reference conditions must be defined (Schaumburg et al., 2004; Pardo et al., 2012) for each water body and biological quality element (BQE; phytoplankton, macrophytes and phytobenthos, benthic invertebrate fauna, and fish fauna). The classification in types is an attempt to organise the abiotic variability of streams (or water bodies) in order to determine areas that are homogeneous regarding a certain number of features, such as climate, altitude, geology, or morphology, that strongly influence the distribution and community composition of aquatic biota (Wimmer et al., 2000). However,

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while the suitability of such an approach was often investigated and well accepted for macroinvertebrates (*e.g.*, Rawer-Jost et al., 2004; Verdonschot and Nijboer, 2004; Verdonschot, 2006; but see Lorenz et al., 2004), the same is not always true for other biological elements.

Among the BQEs that are primary producers, phytobenthos is frequently the only available community in small streams, due to the absence of true phytoplankton and macrophyte vegetation (Eloranta and Soininen, 2002). Diatoms have been selected by most countries in Europe as representative of such a group (Almeida and Feio, 2012; Kelly et al., 2012; Feio et al., 2014). Several studies have demonstrated that diatoms respond to important hydromorphological, chemical, and physical changes in the environment (*e.g.*, Potapova and Charles, 2003; Almeida and Feio, 2012; Feio et al., 2014). Yet, diatoms are also known to react differently than other aquatic elements to streams' abiotic features. For example, in a study conducted by Feio et al. (2007), the macroinvertebrates revealed to be highly associated with the substrate type, diversity of habitats, and water velocity, while diatoms revealed to be highly associated with geology and stream size. That is one of the main problems of the WFD typological approach, as it assumes a community concordance between the BQEs (the use of the same river types to define ecological benchmarks for all BQEs), which is difficult precisely because the various elements respond differently to various water body and catchment features (Paavola et al., 2003; Dolph et al., 2011).

In addition, the establishment of true reference conditions may be a problem in Europe, and also in many other regions of the world, due to a long history of anthropogenic alteration of landscapes and high population densities (Nijboer et al., 2004; Kelly et al., 2012; Feio et al., 2014). Therefore, alternatives to the use of pristine sites to establish benchmarks for the ecological assessment have been discussed and proposed by several authors in recent years (Reynoldson et al., 1997; Stoddard et al., 2006; Hawkins et al., 2010; Birk et al., 2012; Pardo et al., 2012).

Among those, the concept of least disturbed condition (LDC), according to Stoddard et al. (2006), seems potentially useful to define ecological benchmarks for the central-western Portuguese littoral region. As in other lowland/coastal regions, this area has been suffering from intensive land use, urbanisation, industry, and agriculture, and historical data aren't available. To establish the LDC for these regions, a careful definition of what are presently the 'best' conditions, based on a set of explicit criteria, is needed (Stoddard et al., 2006). The 'best' (best available) for the present region are sites with anthropogenic disturbances concerning changes in hydromorphological characteristics such has riparian vegetation, hydrological regime, channelisation, sediment load, and nutrient concentrations. However, applying this concept in highly disturbed regions may result in a reduced number of sites, and consequently in the need to enlarge the target area to include more reference sites. This was what we believe occurred during the implementation of the WFD in Portugal. By then, 15 river types (INAG, 2008) were established by the Portuguese water authority (Portuguese Water Institute, now Agência Portuguesa do Ambiente); however, the entire central-western Portuguese littoral region was included in a single type, the Littoral (L type), since only a few reference sites were used. That probably resulted in the inclusion of a wide variety of streams (see the Study area and sampling sites section) in the L type, with different communities and potentially different reference values for water quality assessment. If reference values are inappropriate, an incorrect quality rating of sites is likely with the attribution of too high or too low quality classes.

Here we discuss and test strategies to overcome the problem of inadequate reference conditions in such highly disturbed regions. Our main hypotheses were, first, that the increase of the sampling sites density, then the refinement of benchmark criteria (to LDC), and the use of diatom assemblages (as the most ubiquitous biological element in this region) could lead to (1) the alteration of the presently accepted reference values for water quality assessment for the L type based on diatoms, and (2) the redefinition of the L type, with its possible division. In order to avoid forcing the biological to the abiotic data or vice-versa, we analysed independently the existence of abiotic (abiotic data only) and biological (diatom assemblages) sub-groups and assessed *a posteriori* the congruence of the sub-groups formed. For this purpose, we used data collected at 55 sites from this region to (1) test the coherence of the L type concerning its abiotic characteristics – *i.e.*, test the existence of sub-groups; (2) establish and apply criteria for the selection of sites on the LDC; (3) verify if the least disturbed diatom assemblages validate the abiotic sub-groups formed in (1), using both taxonomic composition and diatom traits – *i.e.*, if the abiotic grouping of sites (typology) matches the biological grouping; (4) if the sub-groups could be used to define more adequate benchmarks for the biological assessment of streams based on diatoms – namely, using the Portuguese mandatory diatom index for the region in study, the Indice de Polluosensibilité Spécifique (IPS); and (5) recommend, if needed, new types for this region based on abiotic and biological information.

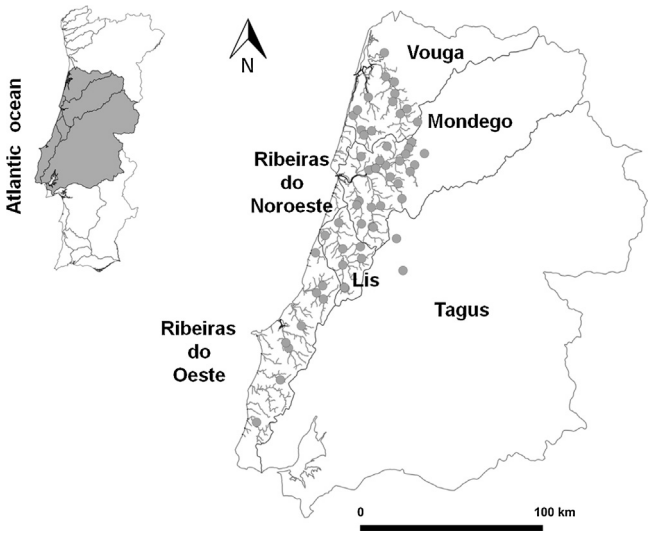

Fig. 1. Location of the study sites (grey circles) in the central Portugal catchments (above left, in grey). The rivers and streams represented (grey lines) are those presently included in the L type.

Methods

Study area and sampling sites

The central-western Portuguese littoral region has an Atlantic-temperate climate characterised by mild temperatures, moderate summers and winters, and precipitation values above 2800 mm year^{-1} (Agência Portuguesa do Ambiente, 2007).

It comprises the catchments of rivers Vouga (V), Mondego (M), Lis (L), and Tagus (T), and the Ribeiras do Oeste (O) and Ribeira do Noroeste (NO). The Ribeiras do Oeste and Ribeiras do Noroeste are small streams discharging directly into the sea, located in the south-western part of the study area (Fig. 1). In general, the L type refers to coastal lowland rivers (mean 40 m a.s.l.) with a wide range of drainage areas (from 10 to 5386 km^2), including small tributaries and coastal streams but also lowland sections of the main rivers Mondego and Vouga (INAG, 2008). In the Portuguese context, these streams are located in an area with a high mean annual temperature (15 °C) and intermediate mean annual precipitation (900 mm)