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Comparison of benthic diatoms from Mediterranean and Atlantic Spanish streams: Community changes in relation to environmental factors

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ABSTRACT

Water and benthic diatom samples were collected in different climatic and geological areas of Spain. Seventy-two sites were sampled in Atlantic Galicia (NW mainland) and 47 sites in the Mediterranean Balearic Islands (NE) in spring season during 2004 and 2006 to identify the most important environmental factors influencing water composition. Furthermore, spring samples were explored to assess differences among diatom assemblages. Streams were selected to cover a wide range of environmental variability. Overall, the Atlantic streams had higher discharge and the Mediterranean streams had higher conductivity. In second instance, in both areas water chemistry was most importantly influenced by diffuse agriculture and local point source organic inputs, leading to high contents of nitrate, ammonium and phosphate. Two-way indicator species analysis (TWINSPAN) produced five diatom groups with different species composition in each study area. The unpolluted streams in the Balearic Islands were characterized by the presence of *Cymbella microchepala* and *Cymbella vulgata*, while in Galicia *Eunotia subarcuatoides, E. intermedia* and *Surirella roba* characterized minimally disturbed streams. *Achnanthidium minutissimum sensu lato* appeared in high abundance in both studied areas. Taxa inhabiting organic polluted Mediterranean streams were *Cocconeis euglypta*, *Navicula veneta*, *Nitzschia inconspicua* and *Planothidium frequentissimum*, while organic loading led to a dominance of *Cocconeis euglypta* and *Eolimna minima* in Atlantic streams. The first two CCA axes explained 82 and 69% of total variance in diatom distribution in Galicia and the Balearic Islands, respectively. In spite of the presence of different diatom communities across Mediterranean–Atlantic streams in undisturbed conditions predictable changes in diatom assemblages do occur in response to organic and nutrient loading gradients.

1. Introduction

Periphyton communities in streams and rivers are an important component of aquatic ecosystems. Benthic algae assimilate dissolved nutrients and use of solar energy to produce available biomass, being key organisms because their position at the base of the grazer's food web, constituting food resources for invertebrates, and fish (Finlay et al., 2002). Periphyton composition and distribution are influenced at local scales by environmental factors such as water chemistry, light, temperature, flow and type of substrate (Stevenson, 1996; Dodds and Biggs, 2002). At larger scales, regional differences in climate characteristics and geology determine distinctive attributes in geomorphology, biogeochemistry and hydrology, influencing water physical conditions and chemical composition and, consequently, the biogeography and species composition of benthic algal assemblages (Pan et al., 2000).

Human activities have caused a range of alterations to the biota in the majority of freshwater ecosystems (Allan and Castillo, 2007), and on the management of water resources insisting for precise and accurate tools (European Union, 2000) to measure the biological integrity of aquatic ecosystems (Cao et al., 2007). Environmental degradation is any change or disturbance to the environment that is perceived to be deleterious or undesirable for biotic communities, in this sense human activities have degraded watersheds, generating awareness and the increase in the scientific development of biomonitoring programs to assess the status of aquatic systems (Kelly and Whitton, 1995; Hering et al., 2006). Direct sewage inputs,

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runoff from fertilized soils, and land erosion through logging activities had a major impact on water resources over the last century (Billen et al., 2001; Wunsan et al., 2002; Ducharne et al., 2007). The increasing availability of nutrients such as nitrate and phosphate (through fertilizers or sewage) in freshwaters, commonly associated with eutrophication, is affecting the productivity and community structure of primary producers in aquatic ecosystems (Leira et al., 2009).

Benthic diatoms have been used in monitoring studies due to their short life cycles and their rapid response to different stressors (Bona et al., 2007). There is an ample body of knowledge on the ecology of diatoms and their optimal environmental conditions and tolerance ranges to water chemistry (Van Dam et al., 1994; Potapova et al., 2004; Schneider et al., 2013). Diatoms are often used for the assessment of nutrient enrichment due to their high sensitivity and specific abilities to respond quickly to this particular environmental change (Hering et al., 2006).

The Iberian Peninsula has two main dominant climatic regions: the Atlantic and the Mediterranean ones, arising by the differences in latitudinal position and the orography. One difference between these hydro-ecoregions is the mean annual precipitation higher in the Atlantic region (Wasson et al., 2007). The area under the Atlantic climate in Spain has permanent streams, with maximum water levels during autumn and winter (Martínez et al., 2000; Pardo and Álvarez, 2006) and mild temperatures due to the proximity of the sea. In contrast, the Mediterranean Islands climate shows irregular rainfall patterns, particularly concentrated in autumn and spring (Pardo and Álvarez, 2006; Sabater et al., 2008), with the result that Mediterranean streams tend to show a marked seasonality in their hydrology (Gasith and Resh, 1999). Many temporary streams in the Balearic Islands have their origin in springs, which are refugia zones for the flora and fauna that colonize the streams when water flow initiates each rainy season (Alvarez and Pardo, 2007; Delgado et al., 2013). Several factors, varying with season, are responsible for the differences found in periphytic algal biomass between Mediterranean and Atlantic streams, such as higher radiation, temperature and water nutrient contents in Mediterranean streams (Pardo and Álvarez, 2006).

Diatom metrics are commonly used to evaluate the ecological status of Spanish rivers (Blanco et al., 2008; Martín et al., 2010; Delgado et al., 2012; Álvarez-Blanco et al., 2013), to integrate and summarize the complex ecology of stream diatom communities. Meanwhile, this is the first study aiming to understand the changes in diatom communities' composition and abundance occurring in response to different environmental conditions that characterize streams and rivers from contrasting different climatic regions.

The purpose of this study was to identify the most important ecological relationships between stream environmental conditions of Mediterranean and Atlantic climates and their diatom communities. The classification the sampling sites was based on their diatom flora. Direct ordination methods were further used to identify key environmental factors related with the diatom-based stream classification. Finally, we tested whether regional differences in diatom community structure, if any, were more evident in reference sites than in variously impacted streams.

Our objectives were: (i) to explore environmental factors that characterize natural and disturbed streams and their diatom composition in Atlantic and Mediterranean streams; (ii) to identify diatom groups along the most relevant organic/nutrients loading gradients in water quality; (iii) to compare the relationship between diatom groups and environmental factors along an increasing gradient of environmental degradation in water quality, and (iv) to ecologically characterize species groups using the analyzed ranges of environmental stream conditions.

2. Materials and methods

2.1. Study area

The Northwest of the Iberian Peninsula (42.5° N 8.1° W) is characterized by a rainy weather with mild temperatures throughout the year, influenced by Atlantic climate. The studied area comprises all the river basins rising within the Galician region (Fig. 1). Most abundant bedrock materials are granite and schist rocks, and granite reliefs dominate the orography, where hills alternate with valleys. The mountain geomorphology and regular precipitation influences rivers and streams leading to regular discharge throughout the year (Delgado et al., 2010).

The Balearic Islands (39°30′ N 3°00′ E) are located in the western part of the Mediterranean Sea (Fig. 1), influenced by the Mediterranean climate, characterized by moderate to low rainfall levels, hot dry summers and cool to cold winters. The seasonal patterns are relatively predictable, but interannual differences can be very large. Annual mean temperatures are around 12.5 °C in winter and 25 °C in summer (Font Tullot, 2007) in this area. In particular, the streams stop flowing during the hottest and dry summer months. This is due to the combination of seasonal rainfall variation, the predominance of a calcareous lithology which promotes infiltration (water stored in subterranean aquifers), and the relief in the island of Majorca, with steep slopes that favors a strong surface runoff.

2.2. Sampling design and selection of reference sites

Databases from the regional governments of Galicia and Balearic Islands were used to evaluate the existence of point and diffuse sources of pollution in the studied areas. Land use cover was evaluated as percentages within the basins draining each site and extracted from level I of CORINE Land Cover (2000) expressed as the percentage of three land-use types (artificial surfaces, agricultural areas and forest and semi-natural areas). A network of minimally disturbed sites, named reference sites, was selected *a priori*. These sites were thought to lack significant pressures such as artificial surfaces (<0.4% of catchment area), agricultural land (<35% of catchment area), sewage effluents, hydromorphological alterations of the stream bank or significant flow regulation following the criteria described in Delgado et al. (2012). Similarly, a number of sites were selected because they were influenced by different degrees of organic and nutrient enrichment degradation, aiming to cover the whole gradient of impairment in the studied areas (Table 1). The criteria used to select the reference sites were those of the Central/Baltic Geographical Intercalibration Group based on the absence of significant pressures (C/B GIG; van De Bund, 2009; Kelly et al., 2009; Pardo et al., 2012).

2.3. Data collection and laboratory procedure

A total of 119 sites were sampled in spring in the two studied areas. 72 sites were sampled once in Galicia in spring 2004 (April and May) and 47 sites were sampled once in Balearic Islands in spring 2006 (May). The sampling network in the Balearic Islands included those streams that have water for period equal or greater than 5 months (more information in Delgado et al., 2012). The sampling design used in this study fulfills the WFD's scientific and technical requirements to evaluate the ecological status of rivers in these two areas (Delgado et al., 2010, 2012).

2.3.1. Physico-chemical variables

Water temperature, pH, dissolved oxygen and electrical conductivity were measured *in situ* with portable meters. Temperature