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Temporal variation in community–environment relationships and stream classifications in benthic diatoms: Implications for bioassessment

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ABSTRACT

Diatom based biomonitoring tools are proven to be a practical way to indicate stream conditions, but only little is known how stable diatom inferred stream classifications are in time. We studied annual variation in diatom community–environment relationships, community structure and diatom indices (Index of Pollution Sensitivity, IPS and Trophic Diatom Index, TDI) during three consecutive years (2010–2012) in four drainage basins distributed in Finland. We also used a cluster analysis to examine if stream classifications resulted in distinct and temporally stable community types. We found only subtle temporal variation in community–environment relationships, nutrient concentrations (N, P) and conductivity consistently being the main factors structuring communities. According to Mantel tests, diatom communities resembled each other significantly at different years, and the values of IPS and TDI indices remained relatively stable in the basins through time. The stream classification based on diatoms also resulted in temporally stable and statistically distinct community types. We thus suggest that sampling of diatoms, e.g., in every three years seems to be a reliable procedure to assess biological water quality. Generally, to choose the correct metrics to assess water quality is essential, and both biological and physicochemical factors should be considered.

Introduction

Poor water quality and impoverishment of aquatic biodiversity are among the greatest environmental challenges of our time. In 2000, the European Union passed the Water Framework Directive (WFD; European Parliament Council, 2000), mandating the use of different organismal groups to monitor the conditions of surface waters. However, the reliability of biological monitoring is influenced by temporal variation in the environment and, consequently, in biotic communities. According to the WFD directions, diatom sampling has usually taken place every three years, but little is known of how representative such sampling is. Streams are prone to disturbances mainly due to substratum instability, rapid changes in hydrological conditions and associated abrasion, high water velocities, and abrasion by suspended sediments (e.g., Tett et al., 1978; Fisher et al., 1982; Biggs and Thomsen, 1995; Stevenson et al., 1996). Thus, streams are also expected to show rapid changes in species occurrences (Stevenson et al., 1996; Potapova and Charles, 2002; Lavoie et al., 2008).

Because of the substantial and rapid changes in hydrological and chemical conditions in streams, benthic diatoms have been found especially useful for stream monitoring in several countries (e.g. Besse-Lototskaya et al., 2011; Jüttner et al., 2012; Stevenson, 2014), including Finland (Eloranta and Soininen, 2002; Virtanen and Soininen, 2012; Korhonen et al., 2013). Diatoms respond to changes in water chemistry with a delay. Therefore, they typically do not react to small and short-term changes in water quality, but better reflect more substantial and long-lasting changes in water chemistry (Lavoie et al., 2008; Smucker and Vis, 2011a; Stevenson, 2014). The ecology of diatoms is relatively well-known (Stevenson et al., 1996; Eloranta and Soininen, 2002; Stevenson, 2014), and the knowledge of their optimal growing conditions is used for assessing water quality. However, the temporal stability of large-scale stream classifications based on diatoms requires further investigation.

Additionally, it is poorly known whether human impacts on streams affect the stability of stream classifications (Smucker and Vis, 2011a; Della Bella et al., 2012; Stevenson, 2014). Land use, agriculture and wastewaters from industry and residential areas, among other factors, affect water quality and thus diatom

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communities, but purely natural mechanisms additionally influence them. Soil and hydrological factors such as precipitation, flow and runoff can explain part of the variation in water quality and diatom communities. When examining stream conditions during longer time periods, it is very likely that both human-driven and hydrological conditions will change over time.

In general, chemical and physical stability and biotic interactions are the main causes of the temporal variability in community composition (e.g. Oberdorff et al., 2001). In stream diatoms, hydrology regulates local extinction and colonization processes, which are among the major factors shaping populations and affecting the results of biological water quality assessments. Extinction and colonization dynamics can influence the responses of populations to environmental change, possibly inducing weakly predictable patterns (e.g. Ozinga et al., 2005). Findings from the relatively few studies addressing temporal variation in stream diatoms have indicated substantial change in community composition over time (Soininen and Eloranta, 2004; Lavoie et al., 2008; Korhonen et al., 2013).

Many surface water quality assessments utilize different classification tools. Stream classifications are useful for many aspects of water resource management, but they should be conducted carefully (Brenden et al., 2008). The use of biological criteria such as diatom community structure to classify stream systems is appealing, because biological communities integrate physicochemical conditions across multiple temporal and spatial scales and, hence, can be sensitive indicators of environmental conditions. However, studies assessing human impacts on stream ecosystems are typically based on a single taxonomic group, typically fish or macroinvertebrates. Despite of the practice, the degree to which such single taxonomic group based surveys can be generalized across other taxonomic groups is not well-understood (Paavola et al., 2003). The complexity of using biotic criteria to classify streams also stems from such classifications being highly dependent on biological data (Naiman et al., 1992), which can be scarce. Conversely, using physical criteria to classify streams has great practical value. Because the physical habitat provides the template for the organization of communities (Southwood, 1977; Townsend and Hildrew, 1994), physical features are also considered acceptable for developing proxies for biologically meaningful classifications (Frissell et al., 1986; Imhof et al., 1996). Both physical and biological criteria should be taken into account when assessing stream conditions, and subjective assessments should be avoided.

Here, the first aim was to examine whether there is annual variation in diatom community–environment relationships in streams located in four drainage basins. The second aim was to examine whether diatom community structures in different years resembled each other. Thirdly, we used cluster analyses to assess whether diatom stream classifications resulted in statistically distinct and temporally stable community types. Fourthly, we examined annual variation in two diatom indices, the IPS (Specific Pollution sensitivity Index) and TDI (Trophic Diatom Index).

Materials and methods

Study area

Diatoms were sampled in three consecutive years (2010–2012) at 40 stream sites located in four separate basins in Finland (Fig. 1). These basins were selected because it was possible to sample them all in a relatively short period of time (2–3 weeks). We sampled nine stream sites in the basins Kokemäenjoki, Kymijoki and Vuoksi and eight stream sites in the basin Vantaanjoki. In addition, we sampled three stream sites in the basin Ingarskilanjoki and two in the basin Porvoonjoki. We combined the data of these two basins to the data of the basin Vantaanjoki, because all these basins were located in the densely populated and intensively cultivated region in southern Finland, and are notably more eutrophic than the other basins.

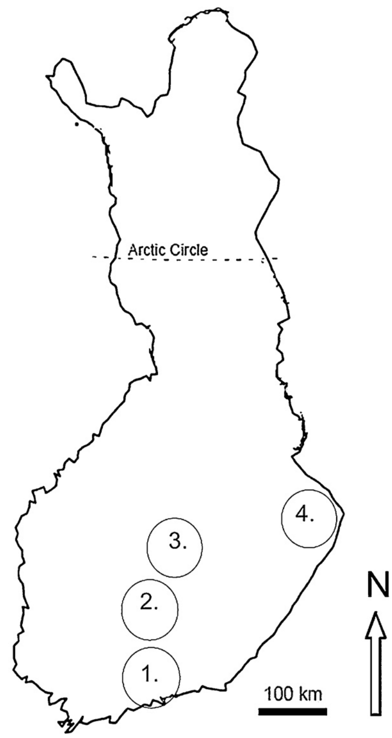

Fig. 1. Map of the study area in Finland with indication of the studied basins. 1 = Vantaanjoki basin, 2 = Kokemäenjoki basin, 3 = Kymijoki basin, and 4 = Vuoksi basin. Vantaanjoki basin refers to three eutrophic basins combined in the analysis.

Sampling and laboratory analysis

The samples were collected at each site once per year in June or July. The same sampling period facilitated the comparison among the samples, as there is also interannual variation in diatom communities (see Korhonen et al., 2013). For sampling, a riffle was divided into ten transects across the stream at intervals of one meter. Ten stones were picked from these transects, one per transect. Diatom samples were collected semi-quantitatively from the stones by using a toothbrush and a soft rubber plate with a hole. For each stone, a 9 cm^2 sample was brushed, and finally all the ten subsamples were pooled into one sample container. Simultaneously to diatom sampling, pH, conductivity and temperature were measured at the stream sites. At each sampling site, we also collected 500 ml water sample for total P and N analyses and 250 ml sample for water color analyses. For the year 2010, the values of current velocity, water depth, shading by the canopy and particle size in the study sites are found in Virtanen and Soininen (2012).

Organic material was removed from the diatom samples by boiling with hydrogen peroxide (30% H_2O_2). Cleaned diatoms were mounted in Naphrax® (Brunel Microscopes Ltd., Chippenham, Wiltshire, UK). A total of 500 frustules per sample were identified to species level using Krammer and Lange-Bertalot (1986–1991). We followed Krammer and Lange-Bertalot's nomenclature except that we used the most recent name for *Achnanthidium minutissimum* (Kützing) Czarnecki (1994). Frustules were counted using phase contrast light microscopy (magnification 1000×). For ten of the total 120 samples, we counted only 300 frustules due to their rarity in the samples. Nutrient concentrations (P and N) were measured