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Taxonomic distinctness along nutrient gradients: More diverse, less diverse or not different from random?

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ABSTRACT

Taxonomic distinctness indices are a family of anthropogenic stress indicators that have been used widely in marine ecosystems; however, their utility in freshwater ecosystems is still unclear. We used two taxonomic distinctness indices and species richness to assess relationships between nutrient gradients and three freshwater taxonomic groups, including diatoms, macrophytes and invertebrates. We found that the indices based on the three organismal groups showed generally rather clear relationships with the nutrient levels, indicating that these indices may bring useful additional information for the purposes of bioassessment. However, the two indices describing taxonomic distinctness showed opposite patterns in relation to nutrient levels. The indices for the three groups of organisms were generally poorly correlated with each other, showing that different organismal groups react differently to anthropogenic stress. Accordingly, taxonomic distinctness indices likely tell us about various aspects of nutrient enrichment of freshwater ecosystems. Our findings also emphasized that the value of these indices may be largely dependent on the organismal group used.

1. Introduction

Aquatic ecosystems, freshwater biodiversity and water resources are threatened by multiple anthropogenic stressors. Hence, there is an urgent need to protect these environments (Dudgeon et al., 2006; Vörösmarty et al., 2010). The protection of aquatic ecosystems requires suitable and efficient bioassessment and monitoring methods, which are usually based on biological communities. The biological communities occupying a site are used in forming indices in the assessment of the ecological state of aquatic ecosystems (Rapport and Hildén, 2013). Many commonly-used measures of diversity, such as species richness, have some well-known weaknesses because they are affected by habitat type and sampling effort (Warwick and Clarke, 1998).

Indices describing the average taxonomic or phylogenetic relatedness within a set of species are an alternative approach for species richness to study changes in the ecosystem state (Clarke and Warwick, 2001; Gallardo et al., 2011), as they enable the comparison of variability in taxonomic relatedness of species across different locations, sampling times and sets of samples. These advantages support the use of taxonomic distinctness (TD) indices in bioassessment (Warwick and Clarke, 1998). Although TD and species richness are both used to describe biodiversity, results based on the two approaches often disagree when multiple environmental gradients and different biotic groups are considered (e.g. Heino et al., 2005). In general, the use of TD indices is based on the assumption of a decrease in TD of biological communities when anthropogenic contamination or stress increases (Warwick and Clarke, 1995).

TD indices were originally developed (Warwick and Clarke, 1995; Clarke and Warwick, 1998, 2001) and further studied extensively (Ellingsen et al., 2005; Tolimieri and Anderson, 2010; Xu et al., 2012) in marine coastal and intertidal environments. Recently, the utility of TD indices have also been tested in freshwater ecosystems, but their applicability for freshwater environmental assessment is still debated. Abellán et al. (2006) suggested that TD indices are not as sensitive as other ecological indices (e.g. richness or Shannon's diversity), but other studies have demonstrated their value as indicators of ecosystem function and responses to environmental changes when compared with other biodiversity indices (Heino et al., 2005; Gallardo et al., 2011). Further, TD of biological

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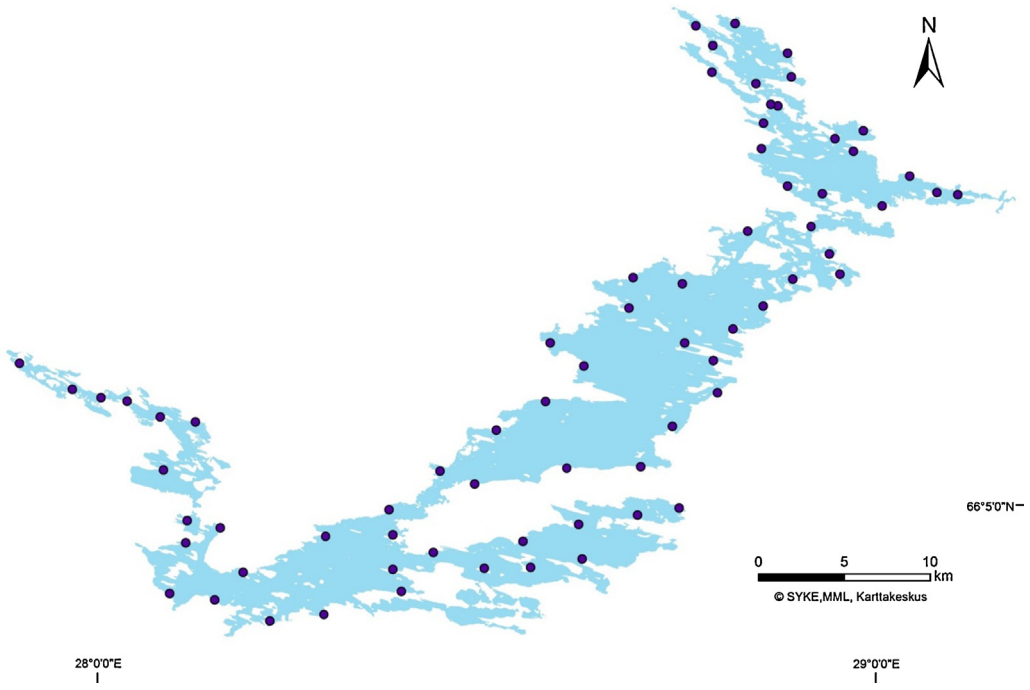

Fig. 1. A map of the study area. There are altogether 70 study sites around the lake system.

communities can portray complex ecological and biological traits of organisms associated with natural environmental variations (Bevilacqua et al., 2009) and may provide information about various aspects of biological diversity (Bevilacqua et al., 2011). Different biological groups have distinct ecological and biological characteristics, and they can therefore react differently to anthropogenic stress (Marzin et al., 2012; Vilmi et al., 2016). Consequently, the relationship between TD indices and anthropogenic stress varies between different biotic groups (Salas et al., 2006; Simaika and Samways, 2011; Jiang et al., 2014; Johnson and Angeler, 2014). Thus, in order to enhance freshwater bioassessment, it is imperative to compare the TD patterns of several commonly-used indicator groups, such as algae, macrophytes and invertebrates.

Our aim was to compare the TD of three commonly used freshwater indicator groups (i.e. littoral diatoms, macrophytes, benthic invertebrates) along nutrient gradients. Specifically, we asked the following questions: (1) How well do variations in nutrient concentrations explain variation in the TD indices? (2) Are there differences between organismal groups in their TD patterns? (3) Does variation in the TD indices differ from that expected by chance? Similarly as Warwick and Clarke (1995) suggested, we assumed that with increasing anthropogenic stress (i.e. increasing nutrient levels), the TD of all organismal groups should decrease. Like the marine environments where the TD indices were originally developed, our focal lake system is large and well-connected. However, as littoral habitats tend to be heterogeneous (e.g. Stoffels et al., 2005) and the processes complex (e.g. Schneider et al., 2014), we expected to find some deviation from the underlying theory and empirical marine studies. Our findings may be useful for the development of future aquatic bioassessment approaches.

2. Material and methods

2.1. The study area

In September 2013, we sampled 70 stony littoral sites around a large lake system (Fig. 1) located in north-eastern Finland. Special effort was made to select sites that were as uniform as possible in physical habitat conditions. The Kitkajärvi lake system is originally oligotrophic, but clear signs of eutrophication have emerged in some parts of the lake system recently (Vilmi et al., 2015). The land use forms around the lake system are mainly forestry, scattered agricultural fields and settlements. In addition to the large areal extent (305 km^2), the high connectivity between sites and the absence of dispersal limitation (see also Palmer et al., 1996; Erős and Campbell Grant, 2015) are predominant features of our study system. Thus, our study area, although being a freshwater lake system, may exhibit similar patterns as shown in marine coastal areas (e.g. Moritz et al., 2013). At each site, the following samples were taken or surveyed in the field: water, diatoms, macrophytes and invertebrates.

2.2. Sampling, laboratory procedures and data processing

2.2.1. Environmental sampling

Water samples were taken at the same locations as the biological samples within two weeks of the biological sampling. Due to time limits, the water samples could not be taken at the same time as biological samples. This was because we thought it was important to analyze the water samples in the laboratory during the same day they were taken in the field. The water samples were taken from a boat a couple of metres offshore, where the water depth was 2–3 m. The sampling depth was always 1 m to prevent sample contamination from disturbed bottom sediments. The water samples were stored in a cool box and transported to the laboratory during the same day. As we were interested in the effects of anthropogenic stress, which appeared in our study system as signs of eutrophication, we used total nitrogen (TN; μg/L; min = 230, max = 720, mean = 333) and total phosphorus (TP; μg/L; min = 5, max = 75, mean = 12) as predictor variables in our analyses. It has to be noted that only a single nutrient sample may cause some uncertainty in nutrient level classifications; however, our limited resources prevented us from taking multiple nutrient samples for each site.

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