Ecological Indicators 95 (2018) 63–74

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Expanding the trait-based concept of benthic diatoms: Development of trait- and species-based indices for conductivity as the master variable of ecological status in continental saline lakes

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ARTICLE INFO

Keywords:
Carpathian basin
Functional approaches
Index
Morphological traits
Soda pans
Water Framework Directive

ABSTRACT

Shallow, saline inland lakes occur over large areas in Central-Europe and they bear exceptionally high biological conservation values. Climate change and anthropogenic activities threaten their natural conditions, or even their existence. These aquatic ecosystems are exposed to multiple stress like naturally high conductivity, pH and nutrient load with very low transparency for light. As they are subjects of criteria set by the EC Water Framework Directive and biological conservation managment, there is an urgent need for developing a suitable quality index for their ecological status assessment. As one major Biological Quality Element, benthic diatoms may provide a reliable basis for their ecological status indication. Here, in a large data set covering the soda lakes of the Carpathian basin, we developed a species- and a trait-based diatom ecological status index. First, based on the weighted average method, we developed a type specific, species-based diatom index (DISP = Diatom Index for Soda Pans) using conductivity as master variable of environmental constrains; and therefore the ecological status in soda lakes. Furthermore, by adapting and improving further the widely-used diatom ecological guild concept, we also developed an alternative trait-based index, which helps avoiding some limitations arising from the obvious complexity of the taxonomy-based approach. Our DISP index covered a significantly larger species pool for index calculation, and responded to conductivity in a more reliable way compared to other available indices. In the trait-based index (TBI) motility, small cell size, and less roundish, more elongated shape as functional and morphological traits indicated pristine ecological conditions (i.e high conductivity) of the soda pans. Planktic life form, high and low ecological guild profiles, as well as the large cell size indicated worse ecological conditions (e.g. lower conductivity). Our study highlights that benthic diatoms provide a reliable basis for ecological status assessment in soda lakes. While both the taxonomic and the functional trait approaches performed well in our analysis, the success of the trait-based approach may enable the use of our TBI index in biomonitoring and conservation management of soda lakes outside of the Carpathian basin, independently of the geographic location.

1. Introduction

Inland saline waters occur at each continent (Williams, 2005). On a European scale, extended saline lake districts are found e.g. in France, Spain, Serbia and Germany. In Hungary, the western margin of the Eurasian steppe zone, saline lakes are found on large areas (1,000,000 ha; Szabó, 1997) in two major hydrological basins: in the Danube-Tisza Interfluve, and in the sourrounding area of Neusiedlersee. The general, limnological explanation of development of such lake districts argues that in endorheic drainage basins precipitation and evaporation coequal in the long term, resulting in alkalization on the carbonaceous bedrock (Kalff, 2002). Besides precipitation, saline inland lakes in the Carpathian basin are fed by saline water from deep-layer aquifers (Mádl-Szőnyi and Tóth, 2009). These lakes are gems of the

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https://doi.org/10.1016/j.ecolind.2018.07.026
Received 22 February 2018; Received in revised form 10 July 2018; Accepted 13 July 2018

Earth's lake diversity and they serve as important refugia for biodiversity (e.g. Pálffy et al., 2014; Tóth et al., 2014). From an ecological point of view, these habitats with their extreme environmental characteristics (Boros et al., 2017) impose multiple stress on their biota. Most dries out completely by late summers; others dry out according to ~10–12 year mesoclimatic cycle (Padisák, 1998). Permanent water cover is more of exception than rule. When their basin is filled with water they are alkaline (pH: ~9–10), saline (conductivity may range from ~3000 to ~60,000 $\mu S\,cm^{-1}$) and inorganically very turbid (Secchi transparency is measurable as few centimeters) (Boros et al., 2017). Since they serve as resting places of migratory birds (some species are also nesting), phosphorus load by the waterfowl can result in permanently high TP values (Stenger-Kovács et al., 2014). Such habitats allow only for low-diversity communities (Padisák et al., 2006; Horváth et al., 2014; Stenger-Kovács et al., 2016) due to pronounced environmental selectivity of best adapted taxa to multiple stress conditions. The role of biotic interactions in shaping community structure under such conditions has only minor importance; biotic communities are predominantly controlled by the physical environment (García et al., 1997).

Diatoms are abundant and widely distributed from freshwaters to marine ecosystems. The community composition of diatoms is well applicable in ecological status indication due to their high sensitivity to the physical and chemical constraints set by different kinds of natural and human impacts. The use of diatoms as ecological indicators can date back to the beginning of the 20th century (Kolkwitz and Marson, 1908). A number of paleoecological and ecological studies evidenced that diatom species composition indicated well past and current changes in the environment (Stoermer and Smol, 2010). Conductivity and pH are the most important variables determining diatom compositions (Soininen, 2007), and the variability of these parameters changes substantially not only on local but also on continental scale (Soininen et al., 2016).

A number of species-based diatom indices have been offered for ecological status assessment. Most of them were developed and tested for river phytobenthos and were included in the software "OMNIDIA" (e.g. IPS, IBD, EPI-D; Coste in Cemagref, 1982-1991; Lenoir and Coste, 1996; Prygiel and Coste, 2000; Dell'Uomo, 2004). Some of the indicies have been implemented into the ecological status assessment of lakes (Kelly and Whitton, 1995; Blanco, 2004; Bolla et al., 2010; Kelly et al., 2006, 2014) according to the requirements of the European Water Framework Directive (EC, 2000). However, diatom indices for lakes are less common and have only been published recently (Jüttner et al., 2010). In Europe, first the trophic diatom index (TI) was developed for German lakes based on alkalinity and trophic status (Hofmann, 1999), and was implemented according to the WFD in Germany (Schaumburg et al., 2004). In Hungary, the trophic diatom index (TDIL) was developed for shallow and freshwater lakes (Stenger-Kovács et al., 2007). Recently, an increasing number of diatom-based ecological analyses appeared for lakes (Crossetti et al., 2013; Kahlert and Gottschalk, 2014; Rimet et al., 2016), but with focus mainly on freshwater and brackish habitats (e.g. Wang et al., 2006; Gell et al., 2002; Della Bella et al., 2007). These indices, however, are, trained" to indicate high salinity levels as a result of human pollution due to e.g. sewage or industrial load, winter de-icing. The same applies for the Halobienindex of Ziemann and Noltig (1999), which approach has recently been implemented in Hungary applying an inverse scaling (Ács et al., 2015), but without a well-documented testing and details. Furthermore, the reliability of this index is highly questionable based on its poor species pool regarding soda lakes. When any of the aforementioned indices are applied in naturally highly saline habitats such as soda pans, they consistently report intolerable or bad ecological status (Stenger-Kovács et al., 2007). However, paradoxically, the most important harm on such lakes is the artificial freshwater input from alien watersheds, which results in decreasing salinity and in, improved ecological status indicated by former diatom indices. In this context, the Sodic Conductivity Index for Lakes (SCIL; Ács, 2007) represented a great step forward, since it was able to assess the status of shallow, large, slightly alkaline lakes in a reliable way. Nevertheless, from an ecological and nature conservation point of view, there has been a compelling demand to develop a reliable diatom index for small, high salinity lakes (Stenger-Kovács et al., 2014; Lengyel et al., 2016; Bolgovics et al., 2017) as characteristic landscape components of the Carpathian region (Boros et al., 2013).

Based on similar physiologies and functional characteristics of taxa, functional (e.g. guilds) and morphological traits may provide a reliable approach (Stevenson et al., 2010) to complete the traditional ecological indication based on taxonomic approach (Lange et al., 2011). On a global scale, diatom species composition may vary significantly among regions, but the guild composition may overlap in a more considerable way. Accordingly, functional approaches may enable us to compare diatom communities with different taxonomical compositions. Diatom guild composition has been found to highly relate to the environment, which approach therefore may enable expressing functional responses of the communities to global environmental changes (Soininen et al., 2016). Following the spread of trait-based approaches in phytoplankton ecology (e.g. Salmaso and Padisák, 2007; Kruk et al., 2010), trait-based ecological status assessments have also been developed for benthic diatoms (e.g. Tapolczai et al., 2017; B.-Béres et al., 2017). At present, the diatom trait-based approach is applied principally in running waters (Lange et al., 2016; Trábert et al., 2017; Novais et al., 2014), whereas authors mainly related trait-based ecological groups of diatoms to major environmental constraints such as nutrients, organic pollution, grazing, shear stress (e.g. Berthon et al., 2011; Lange et al., 2016; Soininen et al., 2016; Tapolczai et al., 2017). As to lakes, the trait-based approach of benthic diatoms has only been applied in very few cases (Gottschalk and Kahlert, 2012; Rimet et al., 2016; Riato et al., 2017; Zorzal-Almeida et al., 2017).

Our aim was (i) to develop a species-based benthic diatom index for small, shallow, naturally highly saline, alkaline lakes; (ii) adapt and further refine the widely-applied diatom ecological guild concept for diatoms of soda lakes in order to identify relevant traits (e.g. morphological) with clear ecological functions; and finally (iii) to develop a trait-based diatom index, which may substitute the taxonomy-based approach with its some obvious limitations. Here, we use the gradient of conductivity as the main proxy of environmental constraints in soda pans along which changes in the species and functional trait compositions may reflect relevant autecological adaptations and therefore indicate ecological functions.

Our hypotheses are that (i) our species-based diatom index performs better than the SCIL index developed for slightly saline lakes; (ii) functional characteristics (e.g. morphological traits, ecological guilds) of diatom taxa alter considerably with conductivity, as proxy for natural *vs.* degraded conditions; (iii) the trait-based diatom index performs as well or even outperforms our species-based diatom index.

2. Material and methods

2.1. Sampling sites, design and laboratory analyses

Altogether 338 parallel samples were collected for phytobenthos and water chemical analyses between 2006 and 2015 from 33 soda pans of the Carpathian basin. The sampling time and its frequency depended on the water supply of the lakes (Fig. 1). Diatom samples were collected each time from the characteristic substrates (macrophytes or mud) at the water depth of 5–10 cm in the littoral region of the pans. Epiphytic diatoms were collected by toothbrush, while epipelic diatoms by pipetting of ~10 cm^3 of superficial layer of the panbed (Cochero et al., 2013). Sample collection followed the recommendations of King et al. (2006) and Kelly et al. (2009). Diatom samples were preserved with ethanol and the samples were kept at pH ~ 7–8 by concentrated HCl to avoid the dissolution of the silica walls. For