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The use of helophytes in assessing eutrophication of temperate lowland lakes: Added value?

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ABSTRACT

Macrophyte-based methods for lake ecological status assessment universally include hydrophytes. Emergent plants (helophytes) are presumed to respond more directly to soil characteristics, wind exposure or shoreline management, hence are usually not considered as reliable indicators of water nutrient enrichment. The aims of the study were to explore the potential role of helophytes as eutrophication indicators and to test whether including or excluding emergent vegetation affects the indicator value of the Ecological State Macrophyte Index (ESMI) used in lake monitoring in Poland. Data on macrophyte composition and abundance (76 hydrophyte and 48 helophyte communities) and water quality from 490 Polish lowland lakes were analysed. Based on the frequency distribution and non-metric multi-dimensional scaling ordination, helophyte communities that exhibited clear trends of occurrence and abundance along the eutrophication gradient and enabled differentiation between lakes in diverse ecological conditions were identified. The effect of emergent vegetation on assessment metric diagnostic capacity was tested using modified index ESMI calculated with helophytes being included (*Comp*ESMI_{TOT}) and excluded (*Comp*$\text{ESMI}_{\text{HYDR}}$) by comparing correlations between both metrics and eutrophication indicators (trophic state indices). Compared to *Comp*ESMI_{TOT}, *Comp*$\text{ESMI}_{\text{HYDR}}$ correlated slightly, though significantly weaker with most of the water quality indicators, and only for TSI_{TP} the difference in metric responses was statistically non-significant. The added diagnostic value of including emergent vegetation was between 0.04 and 0.08 of r^2 increase and this benefit was more pronounced in more degraded lakes. The presented results demonstrated that emergent vegetation provides reliable information on ecosystem ecological conditions and can support assessment of the ecological status of lakes under eutrophication pressure.

1. Introduction

Macrophytes are one of the basic biological elements required or suggested for monitoring and assessing ecological status/integrity/health of surface waters under water quality legislation, both in the European Union (EU Water Framework Directive, WFD; EC, 2000), and in other countries worldwide (e.g. U.S. Clean Water Act, Australian Water Act). This ecological trend in water management has stimulated the intense development of an array of assessment methods that address macrophytes over recent decades, in EU Member States (comprehensive overviews in Poikane et al. (2011, 2015), non-EU European countries (Sager and Lachavanne, 2009), the United States of America (Beck et al., 2010; Moore et al., 2012), New Zealand (Clayton and Edwards, 2006) and Canada (Rooney and Bayley, 2012). The term "aquatic macrophytes" or simply "macrophytes" refers to a diverse group of macroscopic, autotrophic organisms whose life cycle extends or depends on the aqueous medium. Although the term appears in EU and national legislations, the definition of which groups of plant macrophytes consist of is not strictly defined (Brundu, 2015). In the literature, one can find many classifications of macrophytes based on their ecology, growth forms, or reliance on the aquatic environment (e.g., Arber, 1920; Du Rietz, 1921, 1930; Raunkiær, 1934; Luther, 1949; Hejný, 1957; Sculthorpe, 1967; Schuyler, 1984, a comprehensive overviews in den Hartog and van der Velde, 1988 and Best, 1988). Den Hartog and Segal (1964, after den Hartog and van der Velde, 1988) define macrophytes as "plants which are able to achieve their generative cycle when all vegetative parts are submerged or are supported by water (floating leaves), or which occur normally submerged but are induced to reproduce sexually when their vegetative parts are dying due to emersion". Following this definition, some authors distinguish "true aquatic macrophytes" from aquatic macrophytes in a broader sense, including in this narrow category only the growth forms of isoetids,

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elodeids, nymphaeids, lemnids, and charids (Penning et al., 2008); these so-called true aquatic macrophytes are usually referred to as hydrophytes (Toivonen and Huttunen, 1995; Alahuhta et al., 2013; Kolada et al., 2014b). Conversely, in many studies, one can find a very pragmatic division of macrophytes, which, in addition to hydrophytes *sensu lato*, distinguishes also emergent taxa (Golterman et al., 1988; Chambers et al., 2008; Alahuhta et al., 2012; Kolada, 2014; Kolada et al., 2014b). These are defined as plants that are rooted in submersed soils or soils that are periodically inundated, with foliage extending into the air and usually referred to as helophytes.

Hydrophytes, due to their direct response to eutrophication, are universally used in macrophyte-based methods for the ecological status assessment of surface waters (Poikane et al., 2011; Birk et al., 2012; Portielje et al., 2014). Helophytes are presumed to respond more directly to soil characteristics, wind exposure, water level fluctuations, drainage basin ditching or shoreline management (Coops et al., 1994; Partanen and Hellsten, 2005; Partanen et al., 2009) that reduces their perceived value as indicators of water nutrient enrichment (Penning et al., 2008; Alahuhta et al., 2012; Kanninen et al., 2013; Kolada et al., 2014b). Some recent studies on using macrophyte indices for lake assessment explore whether the inclusion of helophytes affects metric-pressure relationships (Alahuhta et al., 2012; Dudley et al., 2013; Kanninen et al., 2013; Kolada et al., 2014b). The reported findings are contradictory, for example, the results reported by Alahuhta et al. (2012, 2013) support the inclusion of helophytes in bioassessment, whereas those by Dudley et al. (2013) and Kanninen et al. (2013) indicate a limited value in doing so. The results of similar studies, conducted for the extensive international dataset (almost 1500 lakes from 12 European countries) were also ambiguous (Kolada et al., 2014b). The inclusion of helophytes improved the performance of macrophyte metric (Ellenberg Index) in Nordic and low alkalinity lakes, whereas the effect in Central-European lakes and those with medium and high alkalinity was statistically non-significant (Kolada et al., 2014b). Moreover, studies by Kolada et al. (2014b) demonstrated that in some countries helophytes are considered an important part of aquatic flora and are included in sampling procedures, whereas in the others they are omitted. This may suggest that the role of emergent vegetation in bioassessment depends on the local conditions, both natural (i.e. climate, altitude, geology) and anthropogenic (i.e. specific pressures), that influence taxonomic composition.

One of the methods for ecological status assessment that involves the entire littoral vegetation, including rush and sedge rush communities, is Ecological State Macrophyte Index (ESMI, Ciecierska and Kolada, 2014). This method has been used in routine lake monitoring in Poland since 2007. It addresses eutrophication pressure, i.e. it allows for the assessment of the ecological status of lakes that are exposed to nutrient enrichment. Emergent vegetation constitutes an important part of the multimetric ESMI as it contributes to both the taxonomic composition component (Pielou's index of evenness; Pielou, 1975) and the abundance component (total vegetated area). Collecting taxonomic data is time consuming and requires trained experts. With this in mind, for cost effective and balanced monitoring, it is essential to explore whether the additional sampling effort implied by helophytes is balanced by the improved information on the ecosystem conditions that they provide.

The aim of this study was to explore the potential role of emergent aquatic and wetland vegetation (helophytes) in the bioassessment as eutrophication indicators. Firstly, I investigated the variability of helophytes' syntaxonomic composition and abundance along eutrophication gradient to determine the sensitivity of emergent vegetation to water quality. Thereafter, I tested whether including or excluding helophytes affects the indicator value of macrophyte metric ESMI used for assessing ecological status of lakes under the eutrophication pressure. With this in mind, the primary focus of the investigation was to determine whether helophytes, that are traditionally included in lake bioassessment in Poland, improve or reduce the reliability of the assessment results.

2. Material and methods

2.1. Data collection

Data on macrophyte taxonomic composition and abundance, physicochemistry and morphometry from 490 Polish lowland lakes surveyed in the years 2003–2012 were analysed. All of the studied lakes are lowland (<200 m a.s.l.), with medium- to high-alkalinity clear waters, but they differ in morphometry and trophy (Table 1). Data on macrophytes were collected within the national lake monitoring programme (430 lakes surveyed in the period 2007–2012), the Polish–Norwegian Research Fund project '*deWELopment*' (11 lakes surveyed in 2009; Kolada et al., 2014a), and other national projects (49 lakes surveyed in 2003–2006; Ciecierska and Kolada, 2014). Data on water quality of 11 lakes were collected within the PNRF project '*deWELopment*' (Soszka and Ochocka, 2011), while those for all the other lakes used in the study were collected within the national lake monitoring programme; the latter are owned by the Chief Inspectorate for Environmental Protection in Poland. Lakes were sampled for water quality in the same year as the vegetation surveys were conducted, four times during the vegetation season, from April to September. In the study, data on total phosphorus (TP), total nitrogen (TN), chlorophyll *a* concentration (Chl*a*), and the Secchi disk reading (SD) were used.

All of the lakes were investigated for macrophytes using the unified field survey procedure based on the belt transect method (Ciecierska and Kolada, 2014; Kolada et al., 2014a). Within the phytolittoral of each lake, the maximum colonisation depth, the mean vegetation coverage, and the relative cover of all of the aquatic and emergent plant communities (stands) were determined. For the identification and classification of aquatic plant communities, the phytosociological approach was applied (Braun-Blanquet, 1964), as this approach is customarily used in vegetation studies in Poland and is an accepted method in lake monitoring practice. The term 'community' was used for homogenous and uniform vegetation areas (phytocoenoses *sensu* Westhoff and van der Maarel, 1973, after Jensén, 1977), named after the dominant species. All of the plant communities/associations/syntaxa were identified, and the syntaxonomic systems established by Brzeg and Wojterska (2001) and Matuszkiewicz (2002) were adopted. The classification system and the terminology for stonewort associations as proposed by Dąmbska (1966) and partly by Brzeg and Wojterska (2001) were used. For botanical nomenclature, the checklists for Polish vascular flora by Rutkowski (2005) and for characeans by Pełechaty and Pukacz (2008) were used.

2.2. Data analysis

In the analysed lakes, 124 macrophyte communities (syntaxa, associations) were recorded including six communities of bryids, five of isoetids, 19 of charophytes, four of ceratophyllids, 27 of elodeids, seven of lemnids, eight of nymphaeids, 42 of rush species and six of wetland species (Table S1 in Supplementary data). Hence, in the study 76 hydrophyte and 48 helophyte syntaxa were included.

The frequency distribution (median, quartiles and range) of helophyte communities in the water quality gradient was analysed and compared to the one derived for hydrophyte communities. Only 66 communities, 37 of hydrophytes and 29 of helophytes,