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The added value of bryophytes and macroalgae in ecological assessment of lakes

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ABSTRACT

Bryophytes and macroalgae have frequently been used as indicators of trace elements and organic pollutants, but their potential as indicators of eutrophication has not been accurately evaluated. Here, I used frequency data of aquatic macrophytes (vascular plants, charophytes, bryophytes and macroalgae) from 233 Swedish lakes to assess the additive value of bryophytes and macroalgae for the assessment of ecological status in lakes. Applying an established approach for boundary setting of total phosphorous (Tot-P) concentrations, 18 of the studied 31 macroalgae and bryophyte species (58.1%) were classified as sensitive species, two as indifferent (6.5%) and 11 as tolerant species (35.5%). Several cryptogam species showed sudden drops in their frequency along the Tot-P gradient (e.g. *Aegagropila linnaei*, *Drepanocaldus sordius* and *Fontinalis antipyretica*). The correlation between a macrophyte-based trophic index and Tot-P concentrations was only marginally higher when calculated with compared to without macroalgae and bryophytes. However, the differences between the trophic index calculated with and without these species, respectively, was significantly higher at Tot-P concentrations < 35 $\mu g\, l^{-1}$. The here presented results suggest macroalgae and bryophytes as important indicators of eutrophication. Hence, they should be routinely integrated into monitoring and ecological assessment of lakes.

1. Introduction

The sensitivity of individual species, growth forms or even whole communities for specific environmental stressors forms the basis for the development of ecological indicators. Aquatic bryophytes are frequently used as indicators of trace elements in lakes and streams (Cenci, 2000; Mouvet et al., 1993; Öhlander et al., 2012; Öhlander et al., 2013; Pekka et al., 2008; Siebert et al., 1996) whereas macroalgae have mainly been used as indicators in coastal areas (Schintu et al., 2010; Vinagre et al., 2016). Macrophytes, including cryptogams such as bryophytes and macroalgae are important for the functioning of lake ecosystems since they amongst others provide habitat and food for many fish and macroinvertebrate species and since they trap and recycle nutrients (Carpenter and Lodge, 1986; Hilt and Gross, 2008; O'Hare et al., 2011). Due to their important role, macrophytes have frequently been used as indicators for water quality (Birk et al., 2012; Birk and Ecke, 2014; Penning et al., 2008a). The growth form of isoetids, including *Isoëtes* spp., *Lobelia dortmanna* and *Litorella uniflora*, has been identified as sensitive to for example eutrophication due to nutrient-induced impoverishment of light regime for these short-stemmed species (Penning et al., 2008b). Generally, for lakes, most studies on macrophyte-based assessment systems focus on vascular plants (Penning et al., 2008b; Poikane, 2009; Schneider and Melzer, 2003), include only few bryophyte or macroalgae species or pool these latter species to lower taxonomic levels (genus or family) (Kolada et al., 2014). Mosses and macroalgae are central for the community structure of macroinvertebrates (Brusven et al., 1990; Parker et al., 2007). Focusing on vascular plants in ecological assessment ignores this important role. However, the non-consideration of cryptogams in lake macrophyte sampling probably rather reflects high demands on taxonomic competence of observers than ignorance of their ecological role. There are only few assessment systems that explicitly include bryophytes and/or macroalgae (e.g. Pall and Moser, 2009), but the additive value of including these cryptogams in the assessment compared to only focusing on vascular plants and charophytes has never been evaluated.

Several studies have identified macrophyte-based indices and metrics that show a response to environmental pressures (Penning et al., 2008a; Poikane, 2009). The effectiveness of such metrics for water quality assessment is however limited if the response is linear. An important step in the assessment process has been the identification of threshold values based on the presence and/or abundance of certain species or communities. Previously, sudden drops in the abundance of

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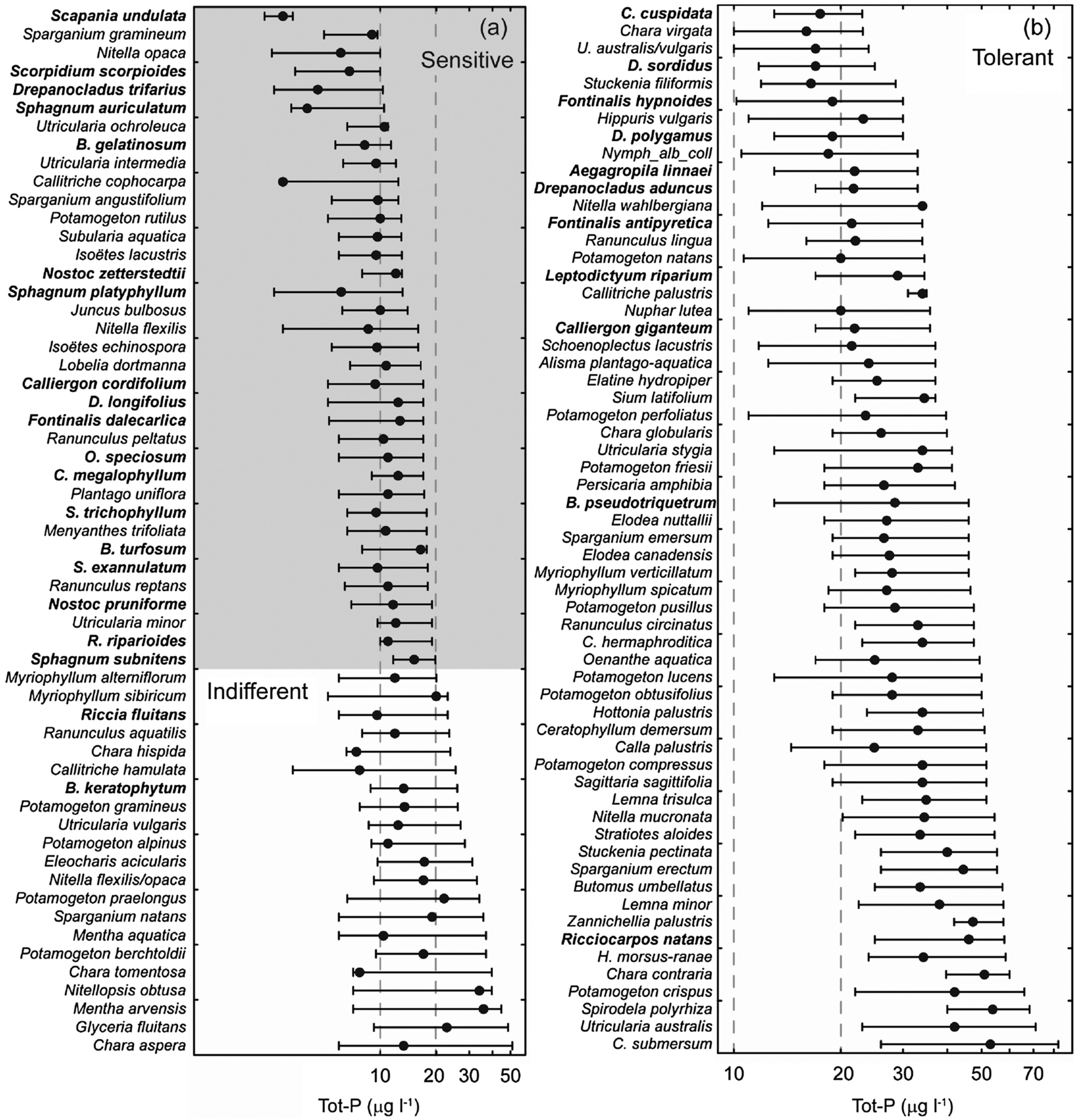

Fig. 1. Response (median ± upper and lower quartiles) of macrophyte species along the Tot-P gradient. Species are sorted according to increasing median values and divided into sensitive (a), indifferent (a) and tolerant (b) species, respectively. Only species occurring in at least three lakes with corresponding water chemistry data are shown. *B. gelatinosum*, *B. turfosum* and *B. keratophytum* represent *Batrachospermum* spp., *B. pseudotriquetrum* is *Bryum pseudotriquetrum*, *C. cuspidata* is *Calliergonella cuspidata*, *C. hermaphroditica* is *Callitriche hermaphroditica*, C. *submersum* is *Ceratophyllum demersum*, *D. longifolius*, *D. polygamous* and *D. sordidus* represent *Drepanocladus* spp., *H. morsus-ranae* is *Hydrocharis morsus-ranae*, Nymph_alb_coll is *Nymphaea alba* coll., *O. speciosum* is *Oxyrrhynchium speciosum*, *R. riparioides* is *Rhynchostegium riparioides*, *S. exannulatum* and *S. trichophyllum* represent *Sarmentypnum* spp., and *U. australis/vulgaris* is *Utricularia australis/vulgaris*. Bryophytes and macroalgae are indicated in bold. Dashed lines indicate Tot-P concentrations of 10 and 20 μg l^{-1}, respectively.

large isoetids, including *Isoëtes* spp., *L. uniflora* and *L. dortmanna*, have been used for the identification of the high-good boundary for the assessment of ecological status according to the EU Water Framework Directive (WFD) (Ecke, 2007; Penning et al., 2008b). In contrast, the other boundaries (good-moderate, moderate-poor, poor-bad) have in most European macrophyte-based assessment systems been identified by purely statistical approaches, for example by using percentiles or equal distance methods (Birk et al., 2012; Poikane, 2009) and suffer from lack in ecological relevance.

The aim of this study using recent and quantitative macrophyte data (including vascular plants, charophytes, macroalgae and bryophytes) from Swedish lakes was three-fold. First, I identified the share of macroalgae and bryophytes among all macrophytes sensitive, indifferent or tolerant, respectively, along a gradient of total phosphorous (Tot-P). Second, I evaluated the frequency of macrophyte species along the Tot-P gradient towards potentially identifying sudden drops of the species' frequencies along the gradient. Finally, I evaluated the additive value of bryophytes and macroalgae for ecological assessment in lakes.

2. Material and methods

2.1. Macrophyte data and water chemistry

The study comprised macrophyte data from 233 Swedish lakes that