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Macrophytes in boreal streams: Characterizing and predicting native occurrence and abundance to assess human impact

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ABSTRACT

Macrophytes are a structurally and functionally essential element of stream ecosystems and therefore indispensable in assessment, protection and restoration of streams. Modelling based on continuous environmental gradients offers a potential approach to predict natural variability of communities and thereby improve detection of anthropogenic community change. Using data from minimally disturbed streams, we described natural macrophyte assemblages in pool and riffle habitats separately and in combination, and explored their variation across large scale environmental gradients. Specifically, we developed RIVPACS-type models to predict the presence and abundance of macrophyte taxa at stream sites in the absence of human influence and, used data from impacted streams to explore the responses of three biotic indices to anthropogenic stress. The indices used, taxonomic completeness (O/E-taxa), a measure of compositional dissimilarity (BC-index) and an index taking into account the abundance of species (AB-index), are based on predicted and observed macrophyte communities. We found that size of the catchment area, altitude, latitude and percentage of lakes in the catchment were the large scale environmental variables that best predicted the natural variation of assemblages. The RIVPACS approach substantially improved both the precision and accuracy to predict the natural communities and the sensitivity to human disturbance. O/E-taxa performed best in relation to the null model decreasing the variation by 20% in pools, 29% in riffles and 32% in combined data. In general, models based on the riffle assemblages performed better than models based on pool assemblages, but including both habitats and predicting abundances instead of only presence/absence yielded the greatest accuracy and sensitivity. Our results support the use of multivariate modelling techniques in predicting reference condition to assess status of stream macrophyte communities.

1. Introduction

Macrophytes constitute a structurally and functionally essential element of stream ecosystems by absorbing nutrients, producing biomass and oxygen (e.g. Wetzel, 2001) and modifying habitats (Gurnell et al., 2012). By trapping fine sediments and slowing down current velocity, they contribute to the colonization of new and survival of the existing stands (French and Chambers, 1996) and provide sheltering habitats for invertebrates and fish (Suren et al., 2000). Macrophytes should hence have an indispensable role in the assessment, restoration and protection of streams.

The aim of modern biological assessment is to evaluate the extent of human impact on biota. For that, it is essential to know the structure of the communities and the associated variation in the absence of human disturbance, i.e. in the reference conditions (Stoddard et al., 2006). Meeting this requirement for stream macrophytes is challenging at least for two reasons. Firstly, streams are spatially and temporally highly variable environments where stochastic events shape the biotic communities (Poff and Ward, 1989; Biggs, 1996; Riis and Biggs, 2003; Franklin et al., 2008). In boreal streams, alternating pool – riffle sections and regular disturbances such as spring floods from snow melt and summer low water levels create the naturally varying conditions (Petersen et al., 1995) that influence macrophyte species composition and abundance (French and Chambers, 1996; Dodkins et al., 2005). Secondly, majority of streams and their biota suffer from human induced alterations in the catchment and impairment of water quality (e.g. Dudgeon et al., 2006; Stoddard et al., 2006) making it difficult to study the purely natural variation in communities.

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In the contemporary bioassessment based on the reference condition approach, the expected biota at a site in the absence of human impact can be modelled using a set of environmental predictor variables that are insensitive to human influence (Hawkins et al., 2000). These predictor variables are chosen so that they best control for the natural variation of biological communities among minimally disturbed reference sites (Hawkins et al., 2000). RIVPACS (River InVertebrate Prediction and Classification System, Moss et al., 1987) and its recent variants, e.g. MACPACS (MACrophyte Prediction And Classification System, Aguiar et al., 2011) represent such multivariate models grounding on the inherently continuous environmental and biotic variation and offering a realistic approach to measure anthropogenic community change (Friberg et al., 2011; Bouleau and Pont, 2015).

Many macrophyte indices have been developed to indicate specific human disturbances such as eutrophication (Demars and Harper, 1998; Birk et al., 2006), even though many studies have suggested only an ambiguous link between macrophyte communities and nutrient enrichment in streams (Demars and Harper, 1998; Hilton et al., 2006; Franklin et al., 2008; Demars et al., 2012). Moreover, the macrophyte communities can be impaired by several alternative stressors individually or in combination and thereby stressor-specific metrics can ignore even significant effects (Kanninen et al., 2013a). Another problem with stressor-specific assessment can be that the metrics are different in scale and hence incomparable (Kanninen et al., 2013a). Therefore, the primary focus of biological status assessment should not be to calibrate biotic metrics to particular environmental changes (which can be observed directly), but to measure ecologically or otherwise important properties of the communities and then quantify anthropogenic impairment of these properties in a unifying manner and scale, independent of the causal factor(s). A further pragmatic requirement is that the metrics conform to legislative stipulations (e.g. Water Framework Directive, WFD, European Commission, 2000). A well-known and widely used example of such measures is taxonomic completeness (Observed-to-Expected-taxa index [O/E-taxa]) which is not calibrated to stressors but only measures change in community composition from reference conditions (Moss et al., 1987; Hawkins, 2006).

In this study, we explored natural variation of boreal stream macrophyte communities across a wide regional scale with the purpose of developing macrophyte assessment and monitoring approach that would also meet the legislative demands set by the WFD. In order to take into account the spatial heterogeneity across different habitats, we assessed the macrophytes separately in riffles and pools and tested if combining the habitats would increase bioassessment performance. Specifically, we first explore the variation attributable to different large scale environmental factors and describe the boreal stream macrophyte reference communities. As large scale factors such as climate, altitude, catchment properties, soil and rock type have been shown to explain natural variation in macrophyte communities (e.g. Baattrup-Pedersen et al., 2006; Alahuhta et al., 2011, 2015), we expected that such factors independent of human disturbance could be efficiently used to predict communities in reference conditions. Last, we compared macrophyte communities in human-disturbed streams with reference communities, using observed to expected ratios of metrics based on the community composition; and further explored the relationship of these metrics to environmental variables indicative of human impact.

2. Material and methods

2.1. Study sites

The study is based on data from 51 reference and 67 impacted streams in the boreal zone across Finland (60°7′–68°24′ N, 21°43′–30°2′ E, Table 1, Fig. 1). The sampled sites belong to the national monitoring network and represent a range of streams from headwaters to larger rivers draining to Baltic Sea with different catchment geology of organic peat, mineral and clay soil. The catchment types were identified according to the national WFD river typology criteria for catchments as peat land (>25% of peat land in the catchment), mineral soil (<25% peat land in the catchment) and clay catchments situated in clay regions in Southern Finland.

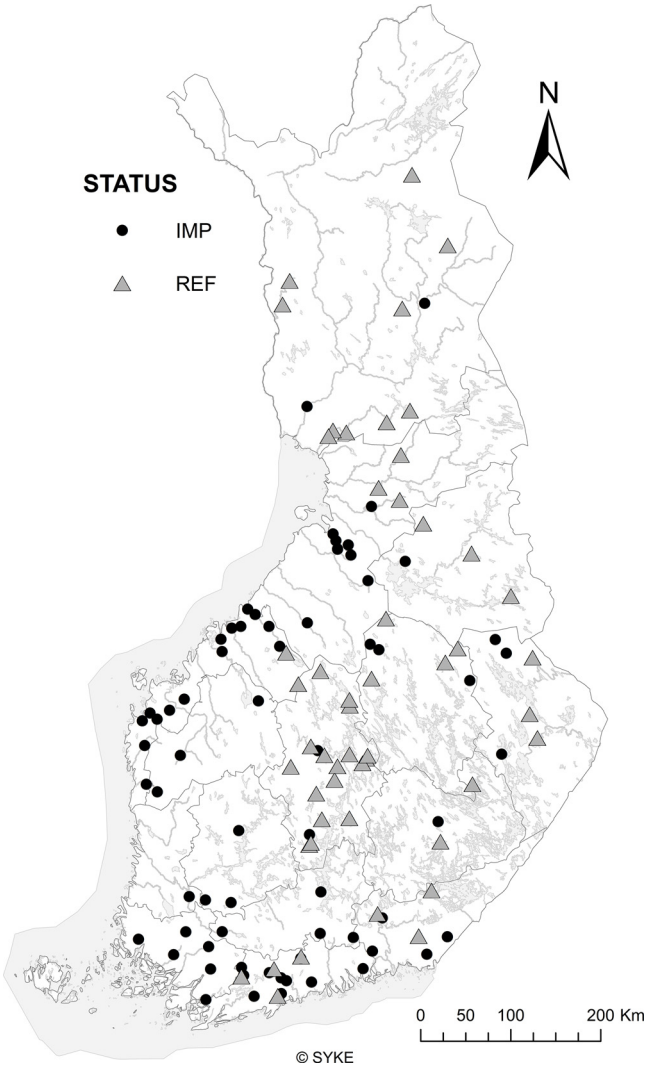

Fig. 1. Location of the study sites within Finland. The grey symbols indicate the reference sites and black dots the impacted sites.

We selected the least impacted (Stoddard et al., 2006) reference (hereafter REF) streams based on expert judgement by local environmental authorities and on pressure criteria (land use, hydro-morphological alteration). The REF streams for mineral and peat land catchments ($N = 47$) were selected according to the national intercalibrated criterion to have less than 10% cover of cultivated area in the catchment (Table 1). The criterion follows the guidance by REFCOND working group (European Commission, 2003) and has been agreed upon by EU member states in the intercalibration process (Van de Bund, 2009). However, in order to have REF-sites ($N = 4$) for the streams in clayish catchments in Southern Finland with more intensive agricultural pressure, we allowed maximum of 17% cover of cultivated area for them (Table 1). We excluded any sites affected by major point-sources of pollution, forestry or hydro-morphological changes. The REF sites had fairly