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Modelling outperforms typologies for establishing reference conditions of boreal lake and stream invertebrate assemblages

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ABSTRACT

Continuous modelling and discrete classification (aka typology) are two approaches commonly used to partition natural, spatial variability, and ultimately gauge anthropogenic effects on biodiversity loss and other valued ecosystem services. Using benthic invertebrate assemblages of boreal lakes and streams, we tested the efficacy of continuous modelling and discrete classification for partitioning natural variability of sites judged to be in reference condition. We anticipated that species distributions and assemblage composition would be more accurately predicted by models in general and specifically that models based on suites of predictor variables would outperform models based on a limited number of variables. Furthermore, we predicted that more flexible typologies would perform better than approaches using sets of mandatory categorical variables. Our results showed that models were more accurate at estimating species distributions and assemblage composition than typologies. Furthermore, models calibrated with only a few typology based variables were as accurate as full models, indicating that the main environmental gradients were captured by the classification variables used in our study. Continuous modelling also had lower incidences of false positives (< 7%) compared to typological approaches (3.8–56%), i.e. a lower frequency of classifying reference sites as possibly impaired. The findings that continuous modelling outperformed discrete classification and that the latter had substantially higher frequencies of false positives is somewhat disconcerting given the relatively widespread use of typologies in bioassessment and management. Misclassification results in the unnecessary use of resources to re-classify sites, or more seriously implementation of unwarranted measures of rehabilitation.

1. Introduction

Lakes and rivers support substantial and unique parts of the Earth's biodiversity and are important for human welfare, livelihood and recreation (Strayer and Dudgeon, 2010). Land use related to agriculture, forestry and urbanisation result in considerable loss of biodiversity and valued ecosystem services, often culminating in socio-economic conflicts. Consequently, multidisciplinary approaches are increasingly needed to identify and resolve conflicts between land use and biodiversity loss (Young et al., 2005) as well as support management decisions (Verdonschot et al., 2013). Knowledge of whether a water body differs from the natural condition or an ecological benchmark, and what has caused the deviation is a fundamental component of designing and implementing assessment programmes (Stevenson et al., 2004). Accordingly, reference conditions are increasingly used to gauge the effects and magnitude of anthropogenic disturbance on the structure and function of aquatic ecosystems. Approaches used to determine reference conditions include the use of historical data (e.g. past studies and paleoreconstruction), discrete classification, modelling and expert judgement (Stoddard et al., 2006; Hawkins et al., 2010a,b; Johnson et al., 2010). Discrete classification (a typology based approach) is frequently used for both lakes and streams, whereas paleoreconstruction is more commonly used for lakes and modelling is more commonly used for streams (Wallin et al., 2003). Expert opinion is frequently used to complement other approaches or to infer expected conditions using measurements from nearby sites (Wallin et al., 2003). Discrete classification and site-specific empirical models are the two methods most commonly used to assess the ecological quality of aquatic systems in Europe and elsewhere (Davies et al., 2000; European Commission, 2000; Wright et al., 2000).

A major distinction between the use discrete classification and modelling for partitioning natural variability is that the former relies on categorical variables, whereas model-based approaches often use continuous variables. In theory, as environmental gradients are generally continuous, models should outperform typology based approaches for characterizing species – environment relationships. Indeed, many

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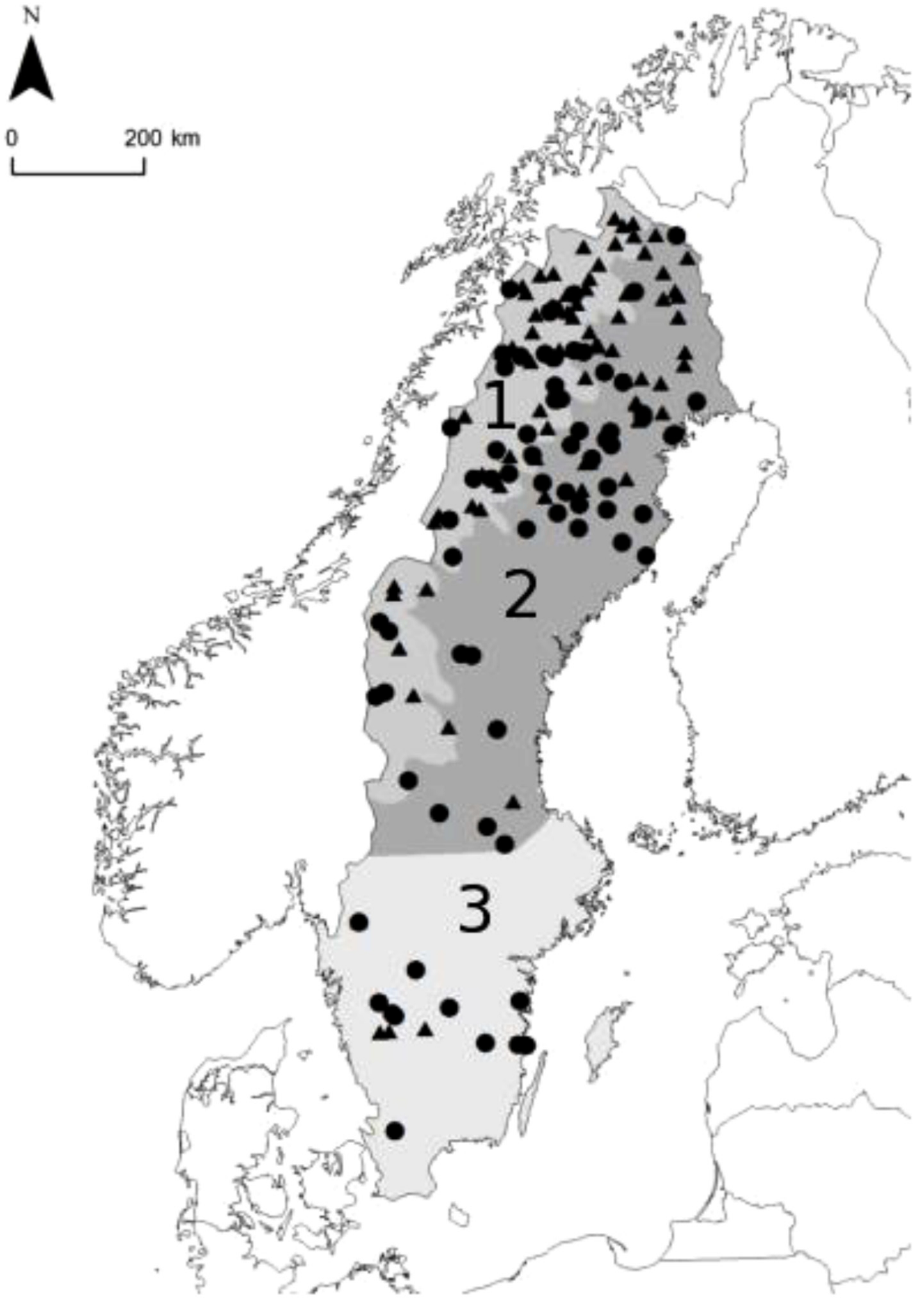

Fig. 1. Map showing the location of the 73 lakes (circles) and the 77 streams (triangles) and ecoregions according to Illies (1978). Borealic Uplands ecoregion in the northwest (1), Fennoscandian Shield ecoregion in the northeast (2) and Central Plains ecoregion in the south (3).

studies have shown continuous models to be more robust than discrete classification for partitioning natural variability of aquatic assemblages (e.g. Davy-Bowker et al., 2006; Mykrä et al., 2008; Aroviita et al., 2009; Hawkins et al., 2010a,b; Rääpysjärvi et al., 2016; Liu and Stevenson, 2017). Nevertheless, despite substantial evidence supporting the use of models for partitioning natural variability, typology based approaches continue to have a strong foothold in European environmental assessments (Nijboer et al., 2004; Johnson et al., 2010). This widespread use has clear historical roots (Thienemann, 1921; Naumann, 1921), but that typologies are a key part of European legislation (European Commission, 2000) has certainly resulted in a strong resurgence and focus on using discrete classification in assessing and managing freshwater ecosystems. Centred on water body types the target of European assessments is good ecological status – defined as only slight deviation from the undisturbed condition of the water body type (European Commission, 2000).

There are a number of strengths and weaknesses of using typological and modelling approaches for characterising natural variability. A major strength of using discrete classification is transparency, or simply put the definition of what constitutes a reference condition is established *a priori* using inclusion/exclusion criteria and reference sites are tangible objects. Both typological and modelling approaches require a sufficient number of samples to accurately quantify species – environment relationships. However, acquiring a suitable sample size is often more problematic for discrete classification than modelling, as the number of sites needed to adequately partition natural variability increases markedly with the number of categories and classes used in a classification scheme (Davy-Bowker et al., 2006; Yuan et al., 2008). Moreover, in areas where human activities have extensively altered the landscape, finding adequate reference sites is often difficult as