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A comparison of ecological optima of soft-bodied benthic algae in Norwegian and Austrian rivers and consequences for river monitoring in Europe

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HIGHLIGHTS

- Norwegian and Austrian rivers share species of soft-bodied benthic algae.
- TP optima in Austrian rivers are greater than in Norwegian rivers for most taxa.
- pH optima in Austrian rivers are greater than in Norwegian rivers for all 21 taxa.
- Nevertheless, TP and pH optima in Norwegian and Austrian rivers are correlated.
- Use of models across ecoregions requires regional testing of species optima.

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ABSTRACT

Alpine and Nordic rivers are often considered as being among the most pristine in Europe. Nevertheless, acidification and eutrophication impact surface waters in these regions. Soft-bodied, i.e. non-diatom, benthic algae are used as indicators for eutrophication and acidification in both Norway and Austria, but consistency of indicator values has never been tested. We compared species optima with respect to pH, conductivity, total phosphorus (TP), and NO_3^--N concentration for 21 species, derived from geographically and temporally extensive datasets from Norway and Austria, respectively. The ranges of all four measured parameters were different between Norway and Austria, with Austria having generally higher values for all measured parameters. Optima for all 21 species with respect to pH, conductivity and NO_3^--N were significantly different between Norway and Austria, while 5 of the 21 taxa showed no significant differences for TP. Nevertheless, species optima for Norway and Austria were significantly correlated with each other for TP, pH and conductivity. This indicates that positions of species optima relative to each other may be stable across ecoregions, in spite of the absolute values of species optima being different. In contrast, optima with respect to NO_3^--N were not correlated, possibly suggesting a lesser importance of NO_3^- in shaping benthic algal assemblages than TP and pH. We conclude that the use of eutrophication and acidification models across different ecoregions may give meaningful results, but requires regional testing of species optima.

1. Introduction

Since the 1980s, nutrient concentrations of surface waters have been reduced in large parts of Central Europe, due to improved waste water treatment, reduction of external nutrient loading, and catchment restoration measures (e.g. River Rhein: Admiraal et al., 1993; Danube: van Giles et al., 2005). Nevertheless eutrophication, manifested in the excessive growth of algae and submerged macrophytes, is still a major problem in many surface waters (Kelly and Whitton, 1998). Likewise, surface water acidification has declined since the early 1990s in response to lower levels of acid deposition (Skjelkvåle et al., 2005). Still, acid precipitation continues to exceed the critical load of many surface waters in sensitive areas such as southern Norway (Wright et al., 2005).

Alpine and Nordic rivers are often regarded as being comparatively non-impacted and oligotrophic, especially when compared to lowland rivers. In an analysis of non-impacted reference sites covering large parts of Europe, Kelly et al. (2012) have documented that diatom communities of Alpine and Nordic river types comprised higher numbers of oligotraphentic reference taxa than reference sites in other ecoregions, as indicated by trophic status indices. Comparable analyses for soft-bodied (SB) benthic algae, i.e. non-diatom algae including cyanobacteria, have never been undertaken.

The Water Framework Directive (WFD; EU, 2000) requires member states of the European Union to regularly assess river quality by using so-called biological quality elements, among these are benthic algae. Most countries in Europe use diatoms alone for assessing benthic algal

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assemblages. However, the validity of this approaches has been questioned (Schneider et al., 2012), and Schneider et al. (2013a) have shown that diatom and soft-bodied benthic algal assemblages respond differently to gradients in pH and TP. Both Norway and Austria have a long tradition in studying soft-bodied benthic algae, and data from research and monitoring studies are readily available in these countries. In Norway, indices based on species-composition of SB benthic algae have been developed for assessment of trophic status (periphyton index of trophic status PIT, Schneider and Lindstrøm, 2011) and acid conditions (acidification index periphyton AIP, Schneider and Lindstrøm, 2009). In Austria, the use of diatoms combined with SB algae is mandatory for ecological quality impairment analyses according to the WFD (Pfister and Pipp, 2013), and the use of diatoms alone (see Rott et al., 2003) is only permitted for regional case studies or when the abundance of SB algae is low. For ecological status classification, three modules (SI (Saprobic Index): Rott et al., 1997; TI (Trophic Index): Rott et al., 1999) and RI (Reference Species Index): Pfister and Pipp, 2013) are calculated and classified, and the worst classification from these three modules determines ecological status.

The WFD also required member states to intercalibrate assessment methods among countries, in order to ensure that all member states of the European Union aim for comparable quality standards in their surface waters (Kelly et al., 2009). Although most benthic algae assessment methods have successfully been intercalibrated, the intercalibration exercise did only include comparisons of index outcomes, not a direct comparison of ecological optima for individual species. For diatoms, such a comparative analysis was done for Sweden and Hungary by Kovács et al. (2006) with the intention to test regional versus interregional applicability of pH and nutrient models.

Besides TP and pH, NO_3^--N and conductivity have also been shown to be related to benthic algal assemblages (Vis et al., 2008; Delgado et al., 2012). We here compare ecological optima of 21 species of SB benthic algae from Austrian and Norwegian rivers with respect to pH, TP, conductivity and NO_3^--N. We hypothesize that the absolute values of the species optima are different between Austrian and Norwegian rivers, but that their relative position is consistent, such that species optima in Norway and Austria are correlated.

2. Methods

2.1. Sampling and analysis of benthic algae

Soft-bodied benthic algae (= algae including cyanobacteria attached to substrata in lotic and lentic waters, but excluding diatoms) were surveyed according to established methods in Austria (Rott et al., 1999; Pfister and Pipp, 2013) and Norway (Lindstrøm et al., 2004; EN 15708, 2009) along a 10 m river channel length using an aquascope (i.e. a bucket with a transparent bottom). At each site, visible benthic algal features were noted and each growth form type was collected. In Norway, all benthic algal samples were taken between June and November. The sampling in Austria was mainly undertaken in spring and autumn (i.e. the seasons of most stable runoff), but some samples were also taken during the peak tourist seasons in summer and winter. In both Norway and Austria, benthic algae were examined under a light microscope (100 to 400 or 1000 times magnification) and identified as close to species level as possible (EN 15708, 2009). Taxonomic congruence (focus on cyanobacteria) was ascertained during a summer meeting in Austria (1986: first author and EA Lindstrøm). Identification literature comprised several floras and monographs (e.g. Komárek and Anagnostidis, 1998, 2005; Eloranta and Kwandrans, 2007; Gutowski and Förster, 2009; John et al., 2011).

2.2. Water chemical analysis

Water chemistry samples in Norway were taken at the sampling sites between one and 24 times within the same year the benthic algal samples were collected, and the results were stored in the database of the Norwegian Institute for Water Research (NIVA). All samples from Norway were analyzed at the Norwegian Institute for Water Research (NIVA) according to Norwegian standard (NS) procedures during all years (pH: NS 4720; conductivity: NS-ISO 7888; total phosphorus (TP): NS 4725; NO_3^--N: NS-EN ISO 10304-1).

In Austria, subsurface water chemistry samples were taken simultaneously with the algal sampling between one and seven times a year. The nutrient analyses were performed at the Limnochemical laboratory (Institute of Ecology, University of Innsbruck) following Austrian standards related to Standard European methods (pH: ÖNORM EN ISO 10523; conductivity: ÖNORM EN 27888; NO_3^--N: ÖNORM EN ISO 10304-1). Total phosphorus was analyzed according to Vogler (1966), a photometric method which is bi-annually intercalibrated with other European laboratories (detection limit 0.5 μg/l) following the regulations of European Guidance standard on interlaboratory comparison for ecological assessment (EN 16101) (bi-annual ringtests).

2.3. Datasets

Benthic algae and water chemistry data originated from numerous projects and were collected between 1981 and 2001 in Austria and between 1976 and 2010 in Norway. Data were stored at the Institute of Botany, University of Innsbruck and the Norwegian Institute of Water Research (NIVA), respectively. For each taxon of SB benthic algae, estimated abundance at each river site is stored in our databases, but for this analysis, we only use presence–absence data in order to avoid any bias arising from potentially inconsistent quantification approaches. In total, we analyzed data from 538 sites in Austria, and 520 sites in Norway, respectively. In cases where one site was sampled over the course of several years, we calculated average water chemical data for the years when a certain species was present. We thus ensured that each site was only represented once for characterization of species optima and ranges. We then selected all common species for which we had water chemical data for all four parameters (TP, pH, conductivity, NO_3^--N) from a minimum of 6 sites in each country (data from > = 20 sites in each country existed for 73 of 84 pairwise comparisons between Norway and Austria; see Appendix 1 for details). In that way, we produced a dataset for 21 species which occur in both Norway and Austria, including 11 cyanobacteria, five green algae, three red algae, one brown alga and one chrysophyte.

The data from Austrian rivers were from 12 of the 15 aquatic bioregions (Moog et al., 2004). For Norway, all river types (defined via calcium and total organic carbon concentration) and all ecoregions occurring in Norway were represented in our dataset (see Schneider (2011) for a description of river types, ecoregions and selection of reference sites). Data from both Austria and Norway span from non-impacted "reference" sites to sites impacted by eutrophication.

2.4. Statistics/data treatment

With the exception of pH, all water chemical data were ln-transformed to improve normality. We used mean values of each water chemical parameter at all sites where a species was present to characterize species optima. Mean values were used instead of median values because we believe these to be a better description of a true species optimum than median values. We do so because "extreme" values likely characterize a rare habitat type instead of a measuring error and thus likely contain more information than error. In addition, most benthic algal indices also use mean instead of median values to characterize species optima.

Since some of the data for individual species still failed to achieve normality and in order to be consistent, we used Mann–Whitney (M–W) U-tests for testing differences in species optima between Norway and Austria. Because each analysis represented a separate hypothesis, there was no need to adjust α for multiple testing (Perneger, 1998). Spearman correlations were used to test for correlations of species optima among