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Land use impacts on stream community composition and concordance along a natural stress gradient

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ABSTRACT

Most ecosystems are subjected to multiple stressors derived from natural and anthropogenic sources and community responses to human disturbance in naturally stressful habitats may differ from those in more benign habitats. We examined the influence of a natural (geology-driven acidity) vs. human-induced stress (land drainage) and their interaction on the composition and concordance of stream diatom, bryophyte and invertebrate communities. To account for differing drainage impacts in circumneutral (sedimentation) and naturally acid (reduced pH and increased metal concentrations) streams we investigated concordance in three groups of streams: reference (circumneutral and naturally acidic reference), circumneutral (reference and drained) and naturally acidic (reference and drained) streams. We expected diatoms to respond more strongly to anthropogenic acidification and more weakly to sedimentation compared to bryophytes and invertebrates. We expected overall strong concordance among the three taxonomic groups, but especially so in reference streams. All three organism groups had distinct species composition in naturally acidic vs. circumneutral streams. Concordance between communities was overall strong, especially so in the reference streams. All groups responded to drainage disturbance in both types of streams. Invertebrates were slightly less responsive to increased acidification in the naturally acidic streams but were more affected by sedimentation in the circumneutral streams than were the other two groups. The natural stressor affected communities more than the anthropogenic stressors. Naturally stressed communities were affected by an anthropogenic stressor as much as those in more benign habitats, although the additional stressor was similar to the initial stress (further reduction of stream pH). Naturally acid streams may need special concern in bioassessment because models based on circumneutral reference sites will likely produce biased predictions for these streams.

1. Introduction

Habitat loss and alteration are among the most detrimental human impacts threatening ecosystems worldwide, and land modification is one of the most important reasons for species extinctions (Chapin et al., 2000; Fischer and Lindenmayer, 2007). Nevertheless, the role of human disturbance in modifying natural communities is complicated by the fact that variation in the type and magnitude of stressors (Crain et al., 2008) and site history (Harding et al., 1998; Andersson et al., 2014) may alter the way that communities respond to environmental change. Furthermore, not all stressors are of anthropogenic origin, but natural perturbations are also common, and communities in even the most pristine habitats often confront some kind of natural stressors. For example, communities in serpentine soils (Harrison et al., 2014) or in the vicinity of mineral deposits (Clements et al., 2000; Schmidt et al., 2012) are exposed to a natural stressor caused by exceptional geochemistry.

Despite the fact that most ecosystems are subjected to multiple simultaneously acting stressors, most studies have focused on the effects of a single stressor on biological responses. The

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combined effect of stressors is difficult to predict based on single-stressor effects, because biotic responses to multiple stressors are often non-additive, causing potential surprises to ecosystem managers (Paine et al., 1998; Vinebrook et al., 2004). Furthermore, most studies on stressed ecosystems have focused on population-level responses (Crain et al., 2008), yet environmental managers mainly deal with community-level perturbations. Studies assessing the independent and interactive effects of simultaneously acting stressors, particularly in natural settings and at the community level, are therefore clearly needed.

Community response to anthropogenic disturbances in naturally stressful habitats may differ from that in more benign habitats. In our previous study, we assessed the effects of natural acidity and land drainage on α and β diversity of stream communities, and detected differing responses by three major organism groups to a combination of stressors (Annala et al., 2014). However, our measure of β diversity did not take into account shifts in species' relative abundances, thus neglecting an important aspect of diversity, because compositional changes may result in altered ecosystem functions (Carlisle and Clements, 2005; Tolkkinen et al., 2013).

Communities are expected to be concordant (i.e. covary along environmental gradients) if they respond similarly to major environmental gradients (Paszkowski and Tonn, 2000; Paavola et al., 2006). This could happen especially in harsh environments where species sorting (i.e. environmental filtering) is likely to be strong (Jabot et al., 2008). The majority of studies on community concordance have focused on terrestrial or lentic ecosystems, and only few studies have assessed concordance in lotic environments along anthropogenic stressor gradients (but see Mykrä et al., 2008; Pace et al., 2012). While there is evidence for strong covariation in lower taxa (e.g. lentic microbial communities; Kent et al., 2007), most studies have found either no or weak concordance between, for example, fish and invertebrates (Jackson and Harvey, 1993; Infante et al., 2009), diatoms and invertebrates (Hirst et al., 2002) and bryophytes and invertebrates (Virtanen et al., 2009). To our knowledge, no previous study has assessed directly concordance among aquatic communities affected by stressors of both natural and anthropogenic origin (but see Hogsden and Harding, 2012). The issue of community concordance is of obvious conservation and management importance, because a high level of concordance among widely differing taxonomic groups might enable the use of one taxonomic group as a surrogate for other, more poorly known groups, in bioassessment and conservation planning.

We examined the influence of a natural (acidity caused by specific geology) vs. human-induced stress (forest drainage) and their interaction on community composition and concordance of stream benthic organisms (diatoms, bryophytes and invertebrates). To identify the key environmental factors shaping each community, we assessed covariation of community structure with major environmental stressor gradients (i.e., community–environment relationships). We expected assemblages in naturally acidic streams to differ from those in circumneutral streams, and diatoms to show the strongest response of the three groups to naturally low pH (Pan et al., 1996; Andrén and Jarlman, 2008), even more so than benthic invertebrates (Collier and Winterbourn, 1987). We also expected diatoms to respond more strongly to forest drainage in the acidic region where the main effect of drainage was reduced water pH and increased metal concentrations. By contrast, bryophytes and invertebrates were expected to respond to drainage in the circumneutral region where drainage caused streambed sedimentation (Annala et al., 2014; Suurkuukka et al., 2014). Finally, we expected overall strong concordance among the three taxonomic groups, but especially so in the reference streams because of the eminently strong natural gradient from circumneutral to acidic streams.

2. Materials and methods

2.1. Study area

Our data consist of 48 streams, 24 of which are situated in the Iijoki drainage basin and the other 24 sites in the adjacent Oulujoki basin in northern Finland between 64° and 66° N latitude and 26° and 29° E longitude (Appendix A). All the streams run through peatlands and mixed riparian forests. The two regions differ in terms of bedrock geology, the Iijoki basin being mostly dominated by gneiss-granites whereas the Oulujoki basin is characterized by frequent occurrence of metal-rich metamorphosed black shale. Streams running through black shale deposits typically have increased metal concentrations and decreased water pH (Loukola-Ruskeenniemi et al., 1998). Study sites in both regions were selected to be as closely similar as possible in regard to in-stream and riparian characteristics. Thus, we are able to compare the responses of stream assemblages to land drainage in areas with contrasting background geology, one with naturally harsh conditions (low pH, high metal concentrations), the other one with circumneutral pH, low metals.

Forestry, particularly drainage ditching, is the major form of land use in both areas. The drainage of peatlands for silvicultural purposes in Finland reached a peak in the 1960s to 1980s. As a consequence, 5.5 million ha of the forest area of Finland has been drained, constituting about 50% of the total peatland area of the country (Peltomaa, 2007). Drainage ditching is practiced to channel surplus water to streams to enhance forest growth but, as a side effect, it alters catchment-scale hydrology, increases sediment load to streams and also increases metal and nutrient concentrations of the stream water (Vuori et al., 1998; Holden et al., 2004).

We chose 12 drained sites [>27% (mean: 58%) of upstream buffer of 100 m × 1000 m drained] and 12 non-drained reference sites [<15% (mean: 6%) of upstream buffer drained] in both areas. All sites were 1st to 2nd order headwater streams. No other land use activities occurred in the upstream catchment of the sites. All sampling focused on stream riffles; for this purpose, a 30-m long section was delineated at each site. All naturally acidic sites run over a black-shale deposit, so that the impact of background geology on stream water chemistry could be clearly detected. However, because of the patchy occurrence of black shale, some variation (range: 3.7–5.9 (mean 5.0), measured during summer low flows) in water pH could not be avoided. The sites were selected using the black-shale deposit maps of Geological Survey of Finland. The circumneutral streams had an average summertime pH of 6.5 (range: 5.4–7.2), the lowest values being observed for the drained sites (see Annala et al., 2014).

2.2. Biological sampling

Diatoms were sampled in autumn 2010. We brushed diatoms off from five randomly selected stones in each site; these subsamples were then pooled into a composite sample for a site (see Kelly et al., 1998). Frustules were cleaned from other material with acid combustion and 500 frustules per site were identified to lowest possible level, usually species. Two sites were omitted from all analyses concerning diatoms due to insufficient sample sizes (<300 valves).

Bryophytes were sampled in June in 2008 or 2010. We have previously shown in the same study area (in partly the same sites) that among-year variation in stream bryophyte assemblage composition is minor (Jyväsjärvi et al., 2014), and as sites from all stream types were sampled in both years, we assume the effect of sampling year on our results to be minor. Ten 50 cm × 50 cm quadrats were placed at each site and aquatic and semi-aquatic bryophyte species were identified in the field; a few problematic identifications were later verified in the laboratory with a microscope. The proportional abundance (% cover) of each species was estimated for