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Does the taxonomic completeness of headwater stream assemblages reflect the conservation status of the riparian forest?

Jussi Jyväsjärvi [a,*], Heli Suurkuukka [a], Risto Virtanen [a], Jukka Aroviita [b], Timo Muotka [a,c]

[a] University of Oulu, Department of Biology, P.O. Box 8000, FI-90014 Oulu University, Finland
[b] Finnish Environment Institute, Freshwater Centre, P.O. Box 413, FI-90014 University of Oulu, Finland
[c] Finnish Environment Institute, Natural Environment Centre, P.O. Box 413, FI-90014 University of Oulu, Finland

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ABSTRACT

Headwater streams are intimately linked to their riparian zones, yet in conservation planning streams have attracted much less attention than riparian forests. We assessed the relation between the conservation status of riparian forests and taxonomic completeness (ratio of observed to expected taxa richness, O/E) of stream bryophytes and benthic invertebrates in fifty northern Finnish headwater streams. The streams represent three levels of riparian modification: pristine old-growth forests (Woodland Key Habitats, WKHs), slightly modified and strongly modified (mainly drainage ditching) forests. Macroinvertebrate O/E ratios were significantly, by about 40%, higher in natural than in modified sites. Bryophyte O/E ratios in strongly modified sites were about half of those in pristine sites (mean O/Es: 0.95 vs. 0.50, respectively) whereas the pristine and slightly modified sites did not differ. O/E ratios of both groups were negatively correlated with fine sediments, indicating drainage as the primary factor impairing stream condition. Eight streams (four pristine, four slightly modified) monitored through six years showed little temporal variability in taxonomic completeness. Nonetheless, inter-annual variability in O/E was sufficient to cause frequent misclassifications of stream status, slightly modified sites being frequently classified as no different from the reference. For macroinvertebrates, sites indicative of high conservation value (CV) were rather evenly distributed among the three status classes, whereas the bryophyte CV index was lower for the strongly modified than for pristine sites. Several sites defined degraded *a priori* scored high values for the CV index of macroinvertebrates. Conservation efforts focusing on small-scale key habitats may therefore be insufficient and need to be complemented by sites that remain beyond protected area networks (WKHs), yet support high conservation value in terms of rare taxa occurrence. Conclusions about the performance of protected area networks should not be based on a single taxonomic group as different groups may yield different assessment outcomes. We also suggest that sites that are in inferior ecological condition (O/E < 1.0) yet support unexpectedly high numbers of rare taxa (CV > 1.0) should be addressed as 'restoration priority sites' that might benefit from in-stream or riparian (or both) restoration.

1. Introduction

Headwater streams support diverse biological communities, provide important ecosystem services (Meyer and Wallace, 2001) and are critically important for downstream ecosystem processes (Gomi et al., 2002; Finn et al., 2011), yet are threatened by multiple anthropogenic stressors, including deterioration of water quality and intensive land use (Richardson and Danehy, 2007). They are intimately linked with the surrounding riparian forests and their food webs are largely fuelled by terrestrial inputs of organic material (Wallace et al., 1997; Nakano and Murakami, 2001). Riparian forests are often referred to as biodiversity hotspots, being included in national conservation networks as 'critical habitats' (USA and Canada; Richardson et al., 2010) or 'Woodland Key Habitats' (WKHs, northern Europe; Timonen et al., 2010). Despite the intimate linkage between streams and their riparian forests, the aquatic component of this ecotone has received much less focus in conservation planning. Suurkuukka et al. (2014) showed recently that the diversity of several lotic organism groups responded positively to small-scale riparian conservation, suggesting that the protection of the riparian forest as a woodland key habitat might be beneficial for stream biodiversity as well. Here, we expand on this issue by (i) using a regional model to predict

* Corresponding author. Tel.: +358 50 3585935.
E-mail address: jussi.jyvasjarvi@oulu.fi (J. Jyväsjärvi).

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the composition of biological assemblages in streams draining unmodified riparian forests (i.e. WKH's), and (ii) testing if these WKH's support aquatic biota of distinctive conservation value.

Species richness is a recognized measure of biodiversity but its use as a key criterion in conservation planning is problematic (e.g. Fleishman et al., 2006). For example, richness is blind to species identities and gives equal emphasis to both rare and common species (Jost, 2007). A potential alternative is to use bioassessment techniques based on the Reference Condition Approach (RCA), where the current biological status is compared to a reference status that represents the 'pristine' or 'best attainable' condition (Stoddard et al., 2006). One of the most widely used RCA-based modeling techniques is the River InVertebrate Prediction and Classification System (RIVPACS; Moss et al., 1987). RIVPACS was originally developed for stream macroinvertebrates, but has since been applied to many other freshwater organisms and habitat types (e.g. Joy and Death, 2002; Mykrä et al., 2007; Jyväsjärvi et al., 2011). The basis of this approach is to use environmental characteristics to predict the species composition of a site in the absence of human impact, and then compare the observed with the predicted species composition (O/E ratio or 'taxonomic completeness'; Hawkins, 2006).

Taxonomic completeness quantifies the occurrence of native biota and can thus be a globally consistent, ecologically meaningful and interpretable measure of biological integrity (Hawkins, 2006). As it is not derived from, or calibrated against, any specific stressor gradient, it is a robust measure of anthropogenic impact on biota, with a potential to unify across stressors, habitats and organisms. Nevertheless, this approach has been rarely applied to conservation biology. In one of the few exceptions, Linke and Norris (2003) introduced an RCA-based method that yields an integrated assessment of the condition and conservation value of a site (see also Hermoso et al., 2009). This technique can be used to identify priority sites, that is, sites where conservation efforts should be targeted. The method uses information on both common (for example, probability of capture in the predictive model ⩾50%) and rare (<50%) taxa. In a related approach, Aroviita et al. (2010) showed that threatened stream macroinvertebrates occurred mainly in sites with the highest taxonomic completeness. A potential caveat in applying RCA-based predictive modeling in conservation context is, however, that the reference condition is often difficult to define and, lacking near-pristine reference sites, 'least impacted' sites must often be used instead (Stoddard et al., 2006). Furthermore, the temporal stability of assessments based on predictive modeling is poorly known. Huttunen et al. (2012) showed that the ecological status of forest streams may change substantially through time, suggesting that assessments based on single-year data may be unreliable. Their study focused on near-pristine streams, however, and it seems feasible that biological assemblages in human-impacted streams may exhibit more inter-annual variability than in corresponding reference streams (see Feio et al., 2010). It is equally possible, however, that human disturbance acts as a strong environmental filter that eliminates sensitive specialists, leaving a subset of generalists able to tolerate the harsh conditions (Chase and Myers, 2011). These assemblages might then exhibit little interannual variability in species composition and relative abundances.

Based on the premise that conservation priorities have been dictated, and will likely continue to be so, by terrestrial biodiversity (Amis et al., 2009), our goal was to assess the relation between the conservation status of the riparian forest and the taxonomic completeness of stream bryophytes and benthic invertebrates in northern Finnish forest streams. We selected these groups because they both are common and functionally important in most headwater streams. Benthic invertebrates are the most frequently used target group in freshwater bioassessment because they are long-lived and relatively sedentary and their communities will thus indicate environmental stress at a meaningful scale, both in time and space. Macroinvertebrate assemblages also comprise a diverse set of species with varying and well known responses to human-induced environmental stress (Rosenberg and Resh, 1993). Bryophytes, by contrast, are rarely used in bioassessment or monitoring but are known to play an important role in nutrient and energy fluxes in streams (Naiman, 1983). They also trap organic material and provide flow refugia for invertebrates (Muotka and Laasonen, 2002; Suren and Winterbourn, 1992) and the presence of bryophytes is a key driver of macroinvertebrate community stability in boreal streams (Mykrä et al., 2011).

We first developed a RIVPACS type predictive model for both taxonomic groups to predict their native species composition. We then used these models to assess the ecological condition of our test sites, composed of fifty headwater streams that were *a priori* classified to three status classes (pristine vs. slightly modified vs. strongly modified sites) by regional environmental authorities based on the level of forestry actions in the riparian forest and the stream channel. The pristine status class (old-growth riparian forests) corresponds to Woodland Key Habitats (WKHs) as defined in the Finnish Forest Act (see Suurkuukka et al., 2014). While we expected both models to readily differentiate between natural and strongly modified sites, we asked two additional fundamental questions. First, does the predictive approach (i) correctly assess pristine sites as non-impacted; and (ii) is it able to differentiate between pristine and slightly modified sites? The latter question is of particular relevance because slightly modified sites might be appropriate targets for riparian and/or in-stream restoration, and reliable identification of such sites would help managers allocate limited resources effectively. We also used a 6-yr data set from a subset of eight streams to assess whether the assessment results for the pristine and slightly modified sites vary differently through time. Specifically, we expected taxonomic completeness to be more variable in human-impacted than in natural streams. Finally, we tested whether sites defined *a priori* as pristine supported a disproportionately high conservation value in terms of rare taxa occurrence, thus reinforcing the usefulness of key habitats in conservation planning.

2. Material and methods

2.1. Study sites

The study was carried out in northern Finland, in headwater tributaries of the River Iijoki (65°20′–65°80′N, 27°08′–28°60′E; 115–280 m a.s.l.; Appendix A). The majority of the catchment is characterized by mixed forests and peatlands, with low mountains occurring in the northern part of the area (for details of catchment characteristics, see Suurkuukka et al., 2014). Fifty study sites were categorized by the Finnish Forest and Park Services and the Centre for Economic Development, Transport and the Environment as one of five inventory status classes reflecting naturalness of the riparian forest and the stream channel (Hyvönen et al., 2005). The classification method is based on six habitat features (see Suurkuukka et al., 2014) describing the physical structure of the forest and the stream channel. Each factor is scored from zero (severely modified) to five (no human impact) and the overall status class of a site is calculated as the mean across the six factors. For the purposes of this study, we reclassified the fifty sites into three inventory status classes: sites in class 1 ($n = 20$ sites) have been heavily modified by forestry, particularly by drainage of peatlands to enhance forest growth. Changes to water chemistry have been relatively minor, but in-stream habitat quality has been degraded by excessive input of fine sediments from the catchment; consequently, the status of