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# Woodland key habitats and stream biodiversity: Does small-scale terrestrial conservation enhance the protection of stream biota?

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ABSTRACT

Riparian forests are biodiversity hotspots and key habitats for forest conservation, yet it is not known if the protection of these habitats also provides protection for stream organisms. We used data from 50 headwater stream-forest systems in northern Finland to address this question. Our study sites formed a gradient from highly modified (by forestry) to old-growth riparian forests. We assessed whether the community structure and diversity of benthic diatoms, aquatic bryophytes, stream macroinvertebrates and red-listed species (bryophytes + invertebrates) responded to riparian habitat alteration and whether habitat classification based on site naturalness is indicative of stream conservation value. Except for diatoms and chironomid larvae, all taxonomic groups studied, as well as red-listed species, responded negatively to site modification, showing peak diversity in unmodified habitats. Also in terms of community composition, most aquatic groups responded to the gradient of site naturalness. These results suggest that woodland key habitats, although initially targeted at the conservation of terrestrial biodiversity, may prove to be valuable for the protection of stream biodiversity as well, extending their potential importance to regional biodiversity conservation.

## 1. Introduction

Freshwater biodiversity is globally threatened, with the trend of biodiversity loss exceeding that in most other ecosystems (Dudgeon et al., 2006; Sala et al., 2000). For example, more than 30% of freshwater fishes are considered endangered and, although the present status of other freshwater taxa is poorly known, the proportion of endangered species is probably even higher in many other groups (Abell, 2002). Headwater streams support unique biological communities and provide important ecosystem services (Finn et al., 2011; Meyer et al., 2007). Nevertheless, they are often grossly underrated in conservation planning, despite being seriously threatened by intensive land use practices (Richardson and Danehy, 2007). In northern Europe, for example, less than 5% of headwater streams remain in near-pristine condition (Raunio et al., 2008), and in many other areas of the world pristine headwaters have practically vanished (Benke, 1990).

Terrestrial and freshwater conservation have traditionally taken separate paths. While this can to some degree be justified (Amis et al., 2009), it is unlikely to be a successful strategy in such a tightly interlinked system as headwater streams and their riparian forests. The dependence of stream food webs on riparian inputs, mainly in the form of autumn-shed leaves and terrestrial invertebrates dropping to the water surface, has been firmly documented (Nakano et al., 1999; Wallace et al., 1997). Recent research has shown that this dependency is reciprocal, however: emerging aquatic insects are an important component of food webs in riparian forests (Nakano and Murakami, 2001) and further beyond in the catchment (Sabo and Power, 2002).

Riparian forests are considered to be of high conservation value by both forest and freshwater scientists and managers, but for partly different reasons. In forest conservation, streamside forests are regarded as regional biodiversity hotspots and important dispersal corridors for terrestrial fauna and flora (Marczak et al., 2010), whereas freshwater managers view them mainly as buffers protecting streams against catchment-scale land use impacts (Richardson and Danehy, 2007; Sweeney et al., 2004). An emerging trend in conservation planning is to protect habitats critical for wholesale biodiversity or, more specifically, for endangered and threatened species. For example, the concept of 'critical habitat' under the Canadian and US legislation (Richardson et al., 2010) and 'woodland key habitats' (WKHs) in northern Europe (Timonen et al., 2010), serve these purposes. In northern Europe, WKHs have become a vital element of forest management. In Finland, for

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example, key habitats have been protected by legislation in the Forest Act which identifies pristine streamside forests as a central component of forest biodiversity. The effectiveness of WKHs in providing protection to forest species has been a source of debate (see Hanski, 2005). While some studies suggest that WKHs have failed to reach their targets (Gustafsson et al., 2004; Pykälä, 2007), others have shown WKHs to support high numbers of threatened species (Gjerde et al., 2004; Perhans et al., 2007) and to enhance the connectivity of protected-area networks (Laita et al., 2010). A recent meta-analysis supported the effectiveness of WKHs, although the effect sizes were overall modest (Timonen et al., 2011).

While the Forest Act and related approaches do not explicitly address freshwater ecosystems, it might be assumed that any protection of streamside forests should also benefit stream biodiversity, particularly when no other significant human activities, like hydropower plants, are present. This would thus be an example of the more general case whereby freshwater habitats are rarely the focus of conservation planning but rather attain protection incidentally as they are included in terrestrial protected areas (Nel et al., 2009; Saunders et al., 2002). This will rarely lead to an optimal outcome: indeed, Herbert et al. (2010) showed recently that the terrestrial conservation network of Michigan, USA, does not represent adequately freshwater conservation priorities. Nevertheless, in such an interlinked system as headwater streams and their riparian forests, protection of the terrestrial component might indeed be beneficial for stream biodiversity. This is also suggested by the finding of Sandin (2009) that benthic macroinvertebrate community composition in a south Swedish river reflected near-stream vegetation more than catchment land use or in-stream habitat factors. In addition to allochthonous energy inputs, riparian forests serve many other important functions: they provide shading for the stream, protect the stream from excessive inputs of nutrients and sediments and, if allowed to mature, supply streams with large wood that is critical in-stream habitat for several lotic organisms (Naiman et al., 2005). Nevertheless, the importance to stream biodiversity of conserving intact riparian forests has been rather assumed than tested for.

We assessed whether small-scale terrestrial biodiversity conservation also provides protection for the stream biota. For this purpose, we used biodiversity inventories from 50 headwater streams in northern Finland. These sites represent a gradient from mature to strongly modified streamside forests, with the best sites corresponding to WKHs as defined in the Finnish Forest Act. Our aims were to (i) determine whether species richness, as well as richness of red-listed species, of three freshwater taxonomic groups, benthic diatoms, bryophytes and macroinvertebrates, reflect the gradient of degradation of the riparian forest; (ii) examine whether community composition of each of the three groups shows differentiation along the same gradient; and to (iii) identify stream-dwelling species whose presence indicates intact riparian forest. Finally, our goal was to test how well a rapid classification method based on the physical structure of the stream channel and its riparian forest mirrors the gradient of forestry-induced environmental degradation and could thus serve as an environmental surrogate in freshwater conservation prioritization.

## 2. Materials and methods

### 2.1. Study sites

The study was carried out in northern Finland (65°20′–65°80′N, 27°08′–28°60′E; altitude 115–280 m AMSL) in the headwaters of the River Iijoki basin (catchment area 14,191 km$^2$; Fig. 1). The bedrock of the area is composed mainly of Archaean granitic rocks and gneisses with some intrusions of mafic and ultramafic rocks. The southeastern part of the area is characterized by granites and Proterotsoic volcanic and sedimentary rocks. Low mountains occur in the northern part of the area, while the majority of the catchment is characterized by mixed forests, peatlands and fine-sediment plains. The area represents a transitional zone between the middle boreal and northern boreal zones.

Headwater streams of the study area were classified by the Finnish Forest and Park Services (Metsähallitus) in 1998–2003 to five status classes reflecting the naturalness of the stream channel and the riparian forest. The classification consisted of nearly 2400 sections (200–1000 m in length) in 257 streams (Hyvönen et al., 2005). The classification method is based on six habitat features (see online Appendix Table A) describing the physical structure of the stream channel and the forest. Each factor is scored from zero (complete alteration) to five (no human impact) and the overall status class of a site is calculated as the mean across the scores of each of the six factors (rounded to nearest integer). Sites in the severely modified class 1 have been heavily subjected to forest management actions, particularly peatland drainage. Site status improves progressively towards class 5, which consists of unmodified (or nearly so) streams and their riparian forests (Appendix Table B). To improve the objectivity and repeatability of the inventories, all field personnel were thoroughly familiarized with the protocol and at least one person in a team had long experience of conducting the inventories. All ten streams in class 5 fulfil the criteria for WKHs as established in national legislation.

The majority of peatlands in Finland have been drained by ditching to support forest growth. During the peak activity in the 1960s and 1970s, about 2500 km$^2$ of pristine peatlands were drained annually (Kenttämies, 2006). The drainage activity then decreased until pristine peatlands were no longer drained by the end of the 1990s; old ditch networks are, however, still maintained and improved in many parts of the country. Historically, ditches were drained directly into the stream which was usually also straightened and slightly broadened to improve the effectiveness of ditches in water removal. Unless regularly maintained, ditches gradually lose their effectiveness and become re-vegetated (Fisher et al., 1996). The full recovery of a disturbed peatland is, however, a very slow process and, depending on local hydrological and topographic conditions, may take from about 15 years to several decades, or even centuries (Zedler, 2000). Peatland drainage alters catchment hydrology (for a review, see Holden et al., 2004) and causes excessive input of fine sediments into the stream, leading to in-stream habitat impairment. Drainage intensity (kilometers of ditches draining into a 500 m long and 25 m wide buffer upstream of a study site) in our study sites was highest in the modified class 1 and lowest in the pristine class 5 (GIS-data derived from the Topographical database of National Land Survey of Finland, 2009a; Appendix Fig. A). We also tested other buffer lengths and widths and calculated drainage intensity for the whole catchment; all these measures were strongly correlated with the 500-m buffer and are therefore not presented here. Another major human impact in the study sites was cutting of the riparian forests, resulting in young, homogenous forests dominated by deciduous trees (Hyvönen et al., 2005).

We followed a stratified random protocol to select the study sites. A pool of sites in each status class that fulfilled the following a priori criteria was first selected. First, all selected reaches had to represent a different tributary of the river Iijoki catchment. Second, sites in different status classes needed to be spatially interspersed (i.e., not forming spatial clusters in separate parts of the study area; see Fig. 1). Third, all sites had to be first-to-second order headwater reaches, being about 50-m long riffle sections with an at least 300-m long upstream buffer consisting of the same status class. Finally, 50 study reaches were randomly selected from this larger