

Effects of River Restoration on Riparian Biodiversity in Secondary Channels of the Pite River, Sweden

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Abstract Between 1850 and 1970, rivers throughout Sweden were channelized to facilitate timber floating. Floatway structures were installed to streamline banks and disconnect flow to secondary channels, resulting in simplified channel morphologies and more homogenous flow regimes. In recent years, local authorities have begun to restore channelized rivers. In this study, we examined the effects of restoration on riparian plant communities at previously disconnected secondary channels of the Pite River. We detected no increase in riparian diversity at restored sites relative to unrestored (i.e., disconnected) sites, but we did observe significant differences in species composition of both vascular plant and bryophyte communities. Disconnected sites featured greater zonation, with mesic-hydric floodplain species represented in plots closest to the stream and mesic-xeric upland species represented in plots farthest from the stream. In contrast, restored sites were most strongly represented by upland species at all distances relative to the stream. These patterns likely result from the increased water levels in reconnected channels where, prior to restoration, upland plants had expanded toward the stream. Nonetheless, the restored fluvial regime has not brought about the development of characteristic flood-adapted plant communities, probably due to the short time interval (ca. 5 years) since

restoration. Previous studies have demonstrated relatively quick responses to similar restoration in single-channel tributaries, but secondary channels may respond differently due to the more buffered hydrologic regimes typically seen in anabranching systems. These findings illustrate how restoration outcomes can vary according to hydrologic, climatic and ecological factors, reinforcing the need for site-specific restoration strategies.

Keywords Biodiversity · Boreal · Bryophyte · Off-channel habitat · Restoration · Riparian · River · Secondary channel · Vegetation

Introduction

Riparian ecosystems are among the most biologically diverse ecosystems on Earth. Riparian areas are influenced by fluvial disturbances such as flooding and sediment deposition, which create dynamic and spatially heterogeneous habitats that support high diversities of species and seral stages (Naiman and Décamps 1997; Ward and others 1999, 2002). Frequent, low-intensity floods limit competitive exclusion by dominant species and create open patches for colonization by opportunistic species (Kimmerer and Allen 1982; Auble and Scott 1998; Pollock and others 1998; Bagstad and others 2005). Fluvial processes also affect soil composition and nutrient capital (Nilsson and Grelsson 1990; Naiman and Décamps 1997; Naiman and others 1998; Nilsson and others 1999) and facilitate the dispersal of plant propagules (Nilsson and others 1991, 2010; Andersson and others 2000; Boedeltje and others 2004; Jansson and others 2005; Vogt and others 2006; Gurnell and others 2008). As a consequence, riparian zones tend to support disproportionately large numbers of plant

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species (Naiman and others 1993; Nilsson and Jansson 1995; Goebel and others 2003) as well as distinct communities of species (Sabo and others 2005) relative to other parts of the landscape.

In most parts of the world, human activities have altered the landscape and disrupted fluvial processes to the extent that riparian ecosystems are also among the world's most threatened (Nilsson and Jansson 1995; Poff and others 1997; Tockner and Stanford 2002). Awareness of these threats and their consequences for biodiversity has stimulated increasing amounts of expenditure and effort directed towards river restoration, especially in Europe, North America and Australia (Bernhardt and others 2005; Palmer and others 2005; Arthington and others 2010). Recent studies in northern Sweden have demonstrated that restoring natural flow regimes can be an effective means of enhancing the diversity of riparian plant communities along small (i.e., 2nd–4th order) streams (Helfield and others 2007), but less is known about the effects of restoration on larger rivers with multiple channels.

In river systems where flow is anabranching (i.e., separated into multiple channels around vegetated islands), secondary channels provide critical habitat functions. Secondary channels contribute substantial amounts of seston and macroinvertebrate drift to riverine food webs (Eckblad and others 1984; Sheaffer and Nickum 1986a; Cellot 1996) while serving as nursery habitats for a variety of fish species (Eckblad and others 1984; Sheaffer and Nickum 1986b). Due to their typically buffered fluvial regimes and lower velocities relative to the main channel, secondary channels are especially important as refuge habitat for juvenile salmonids during periods of high flows (Seegrist and Gard 1972; Tschaplinski and Hartman 1983; Brown and Hartman 1988; Beechie and others 1994). Despite this importance, secondary channels are frequently disconnected from the main channel or otherwise impaired as a consequence of anthropogenic activities such as agriculture, urbanization, flood control and transportation (Roni and others 2002; Nilsson and others 2005). For these reasons, reconnecting secondary channels has been identified as a priority objective for the restoration of large rivers in Europe (e.g., Schropp and Bakker 1998) and North America (e.g., Roni and others 2002), but few studies have characterized the results of such undertakings.

Another aspect of river restoration that remains poorly understood is the response of non-vascular plants. Riparian forests have well-developed and species-rich bryophyte communities (Jonsson 1997; Pharo and Beattie 1997) in which patterns of diversity may be strongly influenced by fluvial disturbance (Kimmerer and Allen 1982). Because bryophytes lack effective mechanisms for regulating water uptake and loss (Proctor 1990), they tend to respond relatively quickly to changes in soil moisture. Consequently,

bryophytes may be useful indicators of changes in flow regime caused by anthropogenic disturbance or restoration (Hylander and others 2002).

In this paper we investigate the effects of restoration on vascular plant and bryophyte communities along secondary channels that were disconnected by stone piers to facilitate timber floating on the Pite River. If disconnected secondary channels respond to flow restoration in the same way that channelized, single-channel tributaries do, we hypothesize that restored channels will feature increased diversity and greater representation of early successional and flood-adapted species, particularly in areas closest to the stream. Through this study we hope to elucidate the relationship between fluvial processes and riparian diversity, and in so doing provide information to guide future restoration efforts.

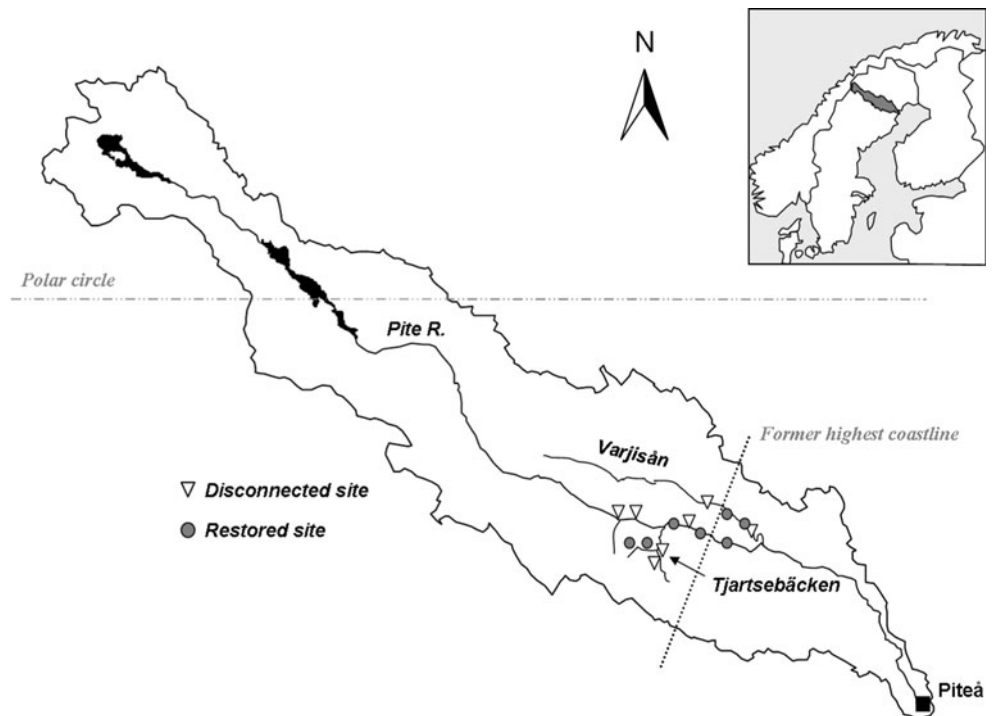
Methods

Study Sites

The Pite River originates in the Scandes Mountains on the border between Sweden and Norway, discharging into the Gulf of Bothnia approximately 300 km to the southeast (65°19'N, 21°29'E; Fig. 1). The Pite watershed is characterized by a boreal forest association in which upland vegetation is predominantly dry to mesic managed forest dominated by Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*), with an understory of dwarf shrubs (e.g., *Vaccinium* spp., *Empetrum nigrum* ssp. *hermaphroditum*), bryophytes and lichens. Riparian zones are comparatively species rich and, although narrow, often exhibit distinct zonation: Low-lying areas bordering stream channels feature a diverse community of graminoid and forb communities, intermediate areas feature shrub communities dominated by willow (*Salix* spp.), and upper areas feature stands of birch (*Betula* spp.) and alder (*Alnus incana*) interspersed with upland spruce or pine forest (Nilsson 1979; Nilsson and others 1994, 2002; Andersson and others 2000). The transition between riparian vegetation, which is generally rich in forb species, and upland forests, which are generally dominated by a few dwarf shrub species, is generally abrupt, roughly corresponding to the elevation of the 2-year spring flood (Nilsson 1983, 1999).

Valley soils in the upper reaches are predominantly glaciofluvial deposits in the form of eskers or nearly flat gravel or sand plains, with frequent boulder deposits and a lack of fine sediments (Wistrand and Lundqvist 1964; Elfström 1988). At 220 m a.s.l., the river crosses the former highest coastline (Lundqvist 1953), the first strip of land that was exposed between the retreating glacial ice

Fig. 1 Study sites in the Pite River system, Sweden



and Ancylus Lake, a pre-stage of the Gulf of Bothnia (Cato 1985; Fromm 1985), below which finer sediments are more common (Elfström 1988). Community composition of riparian vegetation changes in accordance with the substrate, and the most distinct boundary is where the dominant substrate passes from till to fine sediments (Nilsson 1986). High flows occur during the spring snowmelt season (May–June), and low flows occur in winter (November–February), when many tributaries freeze and precipitation occurs primarily as snow. Differences between spring and winter water levels may exceed 5 m (Nilsson 1979), particularly in the lower, more incised reaches of the river (Nilsson 1986). The annual growing season (i.e., days with mean temperature $>5^{\circ}\text{C}$) ranges from <140 days at the headwaters to nearly 170 days at the river's mouth (Ångström 1974).

Like many rivers in northern Sweden, the Pite River has been channelized extensively for timber floating. In the years before timber could be transported on roads (ca. 1850–1970), the Swedish forest industry used rivers and streams for transporting logs to coastal mills. To facilitate more efficient log transport, stream reaches were cleared of boulders and large woody debris and levees of stone and wood were constructed to streamline banks and disconnect (i.e., prevent surface flow from entering) secondary channels (Törnlund 2002; Törnlund and Östlund 2002). Consequences for channelized streams include simplified channel morphologies, more homogeneous flow regimes and decreased flood frequencies (Muotka and Laasonen 2002; Muotka and others 2002; Helfield and others 2007).

Effects are especially pronounced in disconnected side channels, which tend to feature drastic reductions in water level, discharge and flow velocity (JM Helfield and J Engström, pers. obs.). Disconnected side channels are dry or have only shallow, stagnant water throughout most of the year, although they may experience flooding during the highest peak flows (e.g., resulting from spring snowmelt). Consequently, these channels experience fluvial disturbances during only short periods of time, and in some years not at all. In recent years, local authorities have restored many channelized reaches in the Pite River system, using heavy machinery to remove floatway structures and reconnect secondary channels (Nilsson and others 2005). The primary objective of restoration is to enhance aquatic habitat for Atlantic salmon (*Salmo salar*), brown trout (*S. trutta*) and European grayling (*Thymallus thymallus*), but the resulting changes in flow levels and flood frequency are also expected to influence riparian habitats.

Study sites for this project were located in the riparian zones of 14 secondary channels within the Pite watershed, of which seven were disconnected and seven were restored (Fig. 1). Disconnected sites were defined as secondary channels disconnected from the main channel by floatway constructions, in which water levels and flows were significantly reduced relative to the main channel. Restored sites were defined as formerly disconnected secondary channels to which flow had been restored due to removal of floatway constructions at least 5 years prior to data collection (Fig. 2). Additional criteria for site selection included (1) a relatively straight, stable reach with neither

bank predominantly erosive or predominantly depositional, (2) riparian slopes and substrates comparable among sites, (3) relatively intact riparian vegetation, and (4) conditions considered representative of disconnected and restored sites elsewhere in the watershed. Six sites were located on the main stem of the Pite River, whereas eight sites were located on the Pite's two largest tributaries, Tjartsebäcken and Varjisån. Ten sites were located above the former highest coastline.

At each site, a 50 m study reach was delineated at random, with the non-island bank (i.e., the bank farthest from the main channel) chosen for data collection. Four transects were spaced evenly along each reach, originating at the edge of the bankfull channel and extending laterally into the riparian zone for 15 m. Study sites were then characterized in terms of bankfull channel width, channel gradient, bank gradient, channel substrate, bank substrate and overstory composition. Bankfull width was measured with a fibreglass tape at intervals of 10 m along each study reach. Channel gradient was measured along the course of each reach with a hand-held clinometer. Bank gradient was measured along each transect, also with a hand-held clinometer. Channel and bank substrates were classified visually as predominantly boulder, cobble, sand or silt. Overstory composition was measured by recording species, diameter at breast height (dbh) and distance from the bankfull edge for all trees and shrubs >10 cm dbh within an area of 5 × 15 m encompassing each transect. Basal area density was then calculated as the sum of the basal areas of individual overstory plants measured at each site divided by the total area surveyed at that site (i.e., 4 × 5 × 15 m). Individual basal areas were calculated from dbh measurements (i.e., basal area = $\pi \times [\text{dbh}/2]^2$). Physical characteristics and overstory composition of disconnected and restored sites were compared using Mann–Whitney *U* tests.

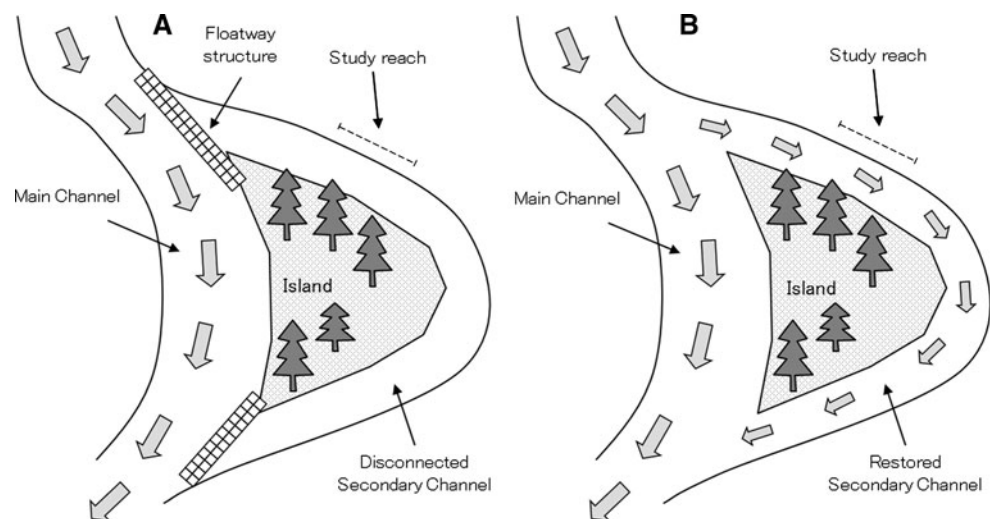
Diversity and Species Composition

Vegetation communities were surveyed in August and September 2004. Along each transect, six quadrats of 1 m² were established at distances of 0–1, 1–2, 2–3, 4–5, 9–10 and 14–15 m from the edge of the bankfull channel. Within each quadrat, we recorded the percent cover of all vascular plant and bryophyte species <2 m in height, as well as the percent cover of bare soil, boulders, large woody debris and standing water.

For both vascular plants and bryophytes, we analyzed species richness, dominance (i.e., the inverse of evenness) and Shannon–Wiener diversity index (H') values at site and plot (i.e., quadrat) scales. At the site scale, species richness was calculated as the total number of species encountered within all of the quadrats at each site. Site-scale species abundance values were expressed as the total area (m²) covered by each species at each site, as calculated from cover percentages observed in all 1 m² quadrats at that site. Site-scale dominance was calculated as the total area covered by the most abundant species at each site divided by total plant cover at that site, with the resulting number indicating the proportion of total plant cover occupied by the most abundant species. The most abundant species at each site was determined according to the sum of cover values observed in all quadrats at that site. Total plant cover at each site was calculated as the sum of cover values for all species in all quadrats at that site. Site-scale H' was calculated using the natural logarithm as per Shannon and Weaver (1949), with proportional abundance (p_i) values calculated as the proportion of total site-scale plant cover occupied by each species at each site. Differences between disconnected and restored sites were analyzed with independent samples *t* tests.

At the plot scale, species richness was calculated as the total number of species encountered within each quadrat, and dominance was calculated as the percent cover of the

Fig. 2 Conceptual plan view of anabranching river with secondary channel disconnected to facilitate timber floating (a) and restored (b). Block arrows indicate surface flow



most abundant species within each quadrat divided by the total plant cover within that quadrat. Total plant cover in each quadrat was calculated by summing the cover percentages recorded for all species within that quadrat. Plot-scale H' was calculated using the natural logarithm as per Shannon and Weaver (1949), with p_i values calculated as the proportion of total plot-scale plant cover occupied by each species within each quadrat. To evaluate the effects of distance from the stream, we conducted two-way analyses of variance (ANOVA) with restoration status (i.e., disconnected vs. restored) and quadrat (i.e., distance) as fixed factors, followed by Tukey's honestly significant difference (HSD) multiple comparisons. Mann–Whitney U tests, t tests and ANOVA were conducted with PASW Statistics version 18 (SPSS Inc., Chicago, IL, USA).

Plot-scale data were also used to analyze patterns of species composition for both vascular plant and bryophyte communities. We used one-way analyses of similarities (ANOSIM) to analyze mean Bray–Curtis dissimilarities in species composition between disconnected and restored quadrats, followed by similarity percentage (SIMPER) analyses to calculate mean Bray–Curtis dissimilarities between all pairs of inter-group (i.e., disconnected vs. restored) quadrats, and to assess the percent contribution of each species to the overall dissimilarity between the two treatments. To evaluate the effects of distance from the stream on species composition, we assigned each quadrat to one of six factor groups representing a combination of restoration status (i.e., disconnected vs. restored) and distance category. Distance categories were near (i.e., 0–1 and 1–2 m), mid (2–3 and 4–5 m) and far (9–10 and 14–15 m). Factor groups were analyzed using one-way ANOSIM followed by pairwise comparisons of disconnected near, disconnected far, restored near and restored far groups. SIMPER analyses were then used to assess the percent contribution of each species to within-group similarities and between-group dissimilarities. For these analyses, the four transects at each site were considered pseudoreplicates rather than true replicates, so quadrats of the same distance at each site were averaged to produce one aggregate plot per distance per site. Vascular plant and bryophyte communities were analyzed separately, using nonstandardized, untransformed abundance data. ANOSIM and SIMPER analyses were conducted with PRIMER for Windows version 6.1.0 (PRIMER-E Ltd., Plymouth, UK).

Results

Site Characteristics

There were no significant differences between disconnected and restored sites in bankfull width, channel

Table 1 Comparisons of site characteristics at disconnected and restored sites

Site characteristic	Disconnected sites	Restored sites	$P(U_{(2),7,7} > U_{\text{obs}})$
Bankfull width (m)	13.1 ± 4.1	18.8 ± 7.2	0.655
Channel gradient	1.3 ± 0.3	2.9 ± 0.7	0.054
Bank gradient (%)	5.5 ± 1.3	5.3 ± 1.3	0.798
Basal area density (m ² ha ⁻¹)	84 ± 58	59 ± 8	0.848
% <i>Picea abies</i> (by m ²)	33 ± 10	30 ± 10	0.701
% <i>Pinus sylvestris</i> (by m ²)	39 ± 14	53 ± 12	0.337

Data are mean values ± 1 standard error. Mann–Whitney U tests indicate no significant differences ($\alpha = 0.05$) between disconnected and restored sites

Table 2 Comparisons of site-scale diversity measures of riparian plant communities at disconnected and restored sites

	Disconnected sites	Restored sites	$P(t_{12(2)} > t_{\text{obs}})$
Vascular plants			
Species richness	39.4 ± 3.1	46.3 ± 5.6	0.309
Dominance	0.30 ± 0.03	0.23 ± 0.06	0.284
Shannon–Wiener index (H')	2.45 ± 0.12	2.92 ± 0.23	0.097
Bryophytes			
Species richness	45.0 ± 5.7	44.4 ± 7.1	0.951
Dominance	0.32 ± 0.03	0.49 ± 0.06	0.031*
Shannon–Wiener index (H')	2.41 ± 0.13	1.70 ± 0.22	0.015*

Data are mean values ± 1 standard error

* Significant differences between disconnected and restored sites ($\alpha = 0.05$) as determined by independent samples t tests

gradient, bank gradient, basal area density or forest overstory composition (Table 1). Similarly, there were no systematic differences in channel or bank substrates, with all substrates characterized primarily by boulders and cobbles overlaid with organic matter. The main difference lay in patterns of streamflow, with the removal of floatway constructions resulting in markedly greater discharges and water levels at restored sites.

Diversity Measures

Among vascular plants, site-scale diversity was not affected by restoration in terms of species richness, dominance or H' (Table 2). At the plot scale, vascular species richness and H' were unaffected by restoration, but restored quadrats exhibited significantly greater levels of dominance relative to disconnected quadrats (Fig. 3; Table 3).

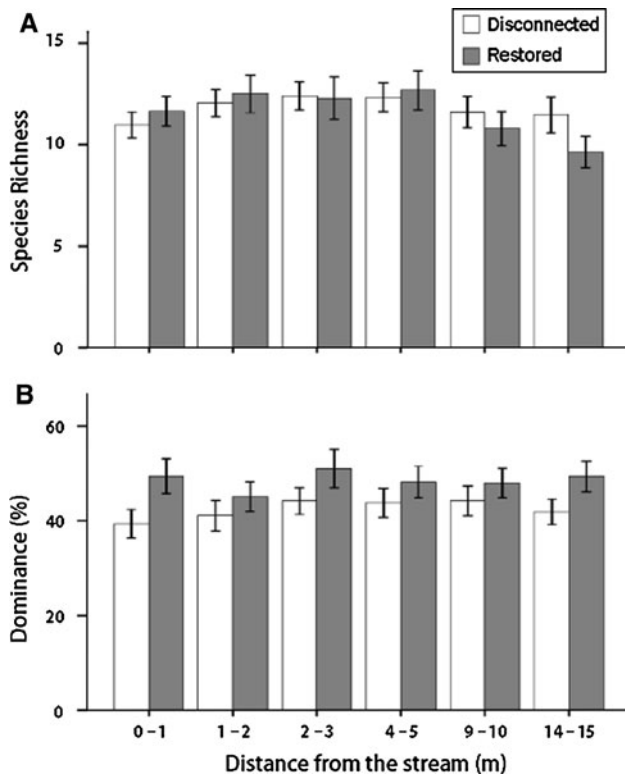


Fig. 3 Species richness (a) and dominance (b) of vascular plants within 1 m² quadrats at various distances from the stream at disconnected and restored sites (mean ± 1 SE)

Among bryophytes, site-scale species richness was unaffected by restoration, but site-scale dominance was significantly greater and H' correspondingly lower at restored sites (Table 2). At the plot scale, species richness and dominance were both significantly greater in restored

quadrats, while H' was unaffected by restoration (Table 3). Plot-scale bryophyte dominance was also significantly influenced by distance from the stream. There were no significant interaction effects between restoration and distance, with quadrats farthest from the stream exhibiting significantly greater levels of dominance and correspondingly lower H' values at both disconnected and restored sites (Fig. 4; Table 3).

Species Composition

Vascular plant species composition was significantly dissimilar between disconnected and restored sites (ANOSIM Global $R = 0.166$, $P = 0.001$). SIMPER analyses indicated a mean dissimilarity of 90.01% between the two groups. Disconnected quadrats were characterized primarily by bare soil, which accounted for 11.44% of the average similarity within the disconnected group, as well as *Rubus saxatilis* (9.82%), *Vaccinium uliginosum* (9.73%), *Molinia caerulea* (8.26%), *Calamagrostis purpurea* (6.27%) and *Filipendula ulmaria* (6.02%). Cumulatively, these species (including bare soil) accounted for 51.54% of the average similarity within the disconnected group. Restored quadrats were characterized primarily by *V. vitis-idaea* (26.58%), *V. uliginosum* (19.74%) and *Juniperus communis* (9.91%), which accounted for a cumulative 56.23% of the average similarity within the restored group (Table 4).

Average similarity values for vascular plant communities were higher within near and far distance categories than within total disconnected or restored groups (Table 4), suggesting some degree of zonation as a function of distance from the stream. At disconnected sites, quadrats closest to the stream were characterized primarily by bare

Table 3 Summary of ANOVA tables examining differences in plot-scale diversity measures for vascular plant and bryophyte communities at disconnected and restored sites

Source	Species richness			Dominance			Shannon–Wiener index (H')		
	df	F	P	df	F	P	df	F	P
Vascular plants									
Restoration	1	0.197	0.658	1	10.504	0.001*	1	3.827	0.051
Distance	5	1.873	0.099	5	0.455	0.810	5	1.083	0.370
Restoration × distance	5	0.688	0.633	5	2.88	0.920	5	0.106	0.991
Error	324			324			324		
Total (corrected)	335			335			335		
Bryophytes									
Restoration	1	5.513	0.019*	1	9.646	0.002*	1	2.679	0.103
Distance	5	2.092	0.066	5	4.531	0.001*	5	4.665	<0.001*
Restoration × distance	5	1.043	0.393	5	0.531	0.753	5	0.616	0.688
Error	324			318			324		
Total (corrected)	335			329			335		

* Significant differences ($\alpha = 0.05$)

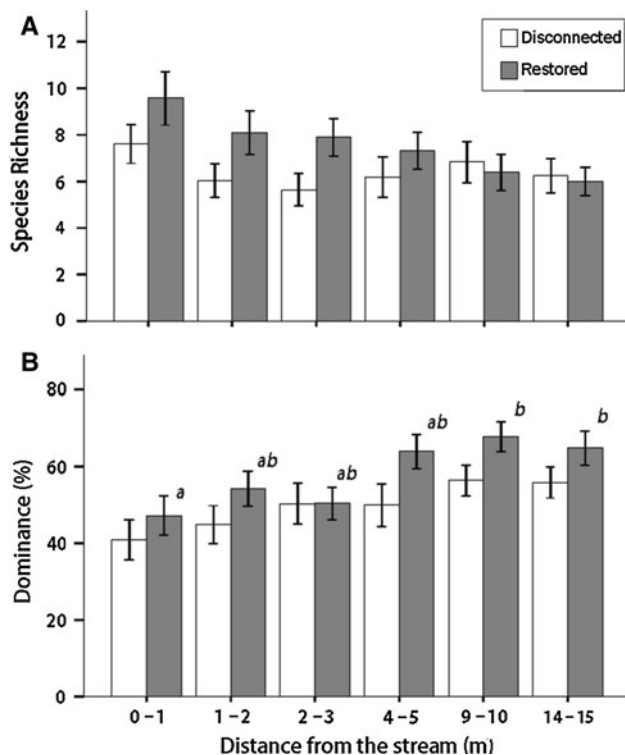


Fig. 4 Species richness (a) and dominance (b) of bryophytes within 1 m² quadrats at various distances from the stream at disconnected and restored sites (mean \pm 1 SE). Superscript letters indicate homogenous subsets, as determined by Tukey's HSD multiple comparisons among distance categories

soil, *M. caerulea*, *F. ulmaria* and *R. saxatilis*, whereas quadrats farthest from the stream featured greater representation of *V. uliginosum*, *C. purpurea* and *V. vitis-idaea*. In contrast, restored sites were strongly represented by *V. uliginosum*, *V. vitis-idaea* and *J. communis* at all distances relative to the stream. Pairwise ANOSIM comparisons indicate that disconnected near quadrats were significantly dissimilar to disconnected far, restored near and restored far quadrats, but no significant dissimilarities were detected between restored near and restored far quadrats, or between restored near and disconnected far quadrats (Table 5).

Bryophyte communities also differed significantly between disconnected and restored sites (ANOSIM Global $R = 0.139$, $P = 0.001$). SIMPER analyses indicated a mean dissimilarity of 90.54% between the two groups. Disconnected quadrats were characterized primarily by *Hylocomium splendens* (20.78%), *Pleurozium schreberi* (18.12%), and *Sanionia uncinata* (15.44%), which accounted for a cumulative 54.33% of the average similarity within the disconnected group. Restored quadrats were also characterized by *H. splendens* (49.58%) and *P. schreberi* (37.11%), which accounted for a cumulative 86.70% of the average similarity within the group (Table 6). *H. splendens* and *P. schreberi* accounted for the

greatest proportion (49.77%, cumulatively) of the total dissimilarity between disconnected and restored groups, both of which were more abundant at restored sites.

As with vascular plants, bryophyte communities exhibited zonation as a function of distance from the stream, as suggested by higher similarity values within near and far distance categories relative to total disconnected or restored groups (Table 6). At disconnected sites, quadrats closest to the stream were characterized by *Campyllum stellatum*, *Campyllum protensum*, *S. uncinata*, *Sphagnum warnstorffii* and *Calliergon cordifolium*, as well as *H. splendens* and *P. schreberi*. In contrast, *H. splendens* and *P. schreberi* were dominant in quadrats farthest from the stream at disconnected sites, and at all distances relative to the stream at restored sites. As with vascular plants, pairwise ANOSIM comparisons indicated no significant dissimilarity in bryophyte community composition between disconnected far and restored near quadrats (Table 7).

Discussion and Conclusions

The results of this study suggest that restoring flow in disconnected secondary channels has not resulted in enhanced diversity in riparian plant communities. If anything, diversity was lower at restored sites, as evidenced by increased levels of dominance in both vascular plants and bryophytes (Tables 2, 3). Although plot-scale bryophyte richness was increased in restored quadrats, the lack of a corresponding increase in H' values suggests that this increase in richness was offset by increased dominance (Table 3). Less equivocal were the differences in species composition observed between disconnected and restored sites, which suggest broad differences in habitat characteristics rather than subtle differences in competitive dynamics. The fact that species composition differed significantly between disconnected near and disconnected far quadrats, but not between restored near and restored far or between restored near and disconnected far quadrats, suggests that zonation in relation to the stream channel was less pronounced at restored sites. At disconnected sites, plots closest to the stream featured an assemblage of species characteristic of mesic–hydric floodplain environments (i.e., *M. caerulea*, *F. ulmaria*, *R. saxatilis*, *C. stellatum*, *C. protensum*, *S. uncinata*, *S. warnstorffii*, *C. cordifolium*), whereas plots farthest from the stream featured an assemblage more typical of mesic–xeric upland forests (i.e., *V. vitis-idaea*, *H. splendens* and *P. schreberi*; see Fremstad 1976, 1978; Hallingbäck 1996; Mossberg and Stenberg 2003; Hylander and Dynesius 2006). In contrast, restored sites featured upland species assemblages at all distances relative to the stream. These patterns likely result from the changes in water level brought about by floatway

Table 4 Results of similarity percentage (SIMPER) analyses characterizing species composition of vascular plant communities in quadrats near to (i.e., 0–2 m) and far from (i.e., 9–15 m) the stream at disconnected and restored sites

Group	Disconnected sites			Restored sites		
	Similarity	Characteristic species	%	Similarity	Characteristic species	%
Near	20.64	Bare soil	23.31	21.36	<i>Vaccinium uliginosum</i>	14.93
		<i>Molinia caerulea</i>	14.04		<i>Molinia caerulea</i>	14.23
		<i>Filipendula ulmaria</i>	7.16		<i>Juniperus communis</i>	12.26
		<i>Rubus saxatilis</i>	6.28		<i>Vaccinium vitis-idaea</i>	9.78
		Cumulative	50.79		Cumulative	51.21
Far	20.98	Bare soil	16.84	26.54	<i>Vaccinium vitis-idaea</i>	28.38
		<i>Vaccinium uliginosum</i>	14.57		<i>Vaccinium uliginosum</i>	21.14
		<i>Calamagrostis purpurea</i>	8.19		<i>Juniperus communis</i>	5.80
		<i>Vaccinium vitis-idaea</i>	7.18			
		<i>Rubus saxatilis</i>	5.39			
Total	10.80	Cumulative	52.17	16.20	Cumulative	55.32
		Bare soil	11.44		<i>Vaccinium vitis-idaea</i>	26.58
		<i>Rubus saxatilis</i>	9.82		<i>Vaccinium uliginosum</i>	19.74
		<i>Vaccinium uliginosum</i>	9.73		<i>Juniperus communis</i>	9.91
		<i>Molinia caerulea</i>	8.26			
		<i>Calamagrostis purpurea</i>	6.27			
		<i>Filipendula ulmaria</i>	6.02			
		Cumulative	51.54		Cumulative	56.23

Similarity values are mean Bray–Curtis similarity among quadrats within each group. Characteristic species are species accounting for >50%, cumulatively, of mean similarity within each group. Percentage (%) values are percent contributions of each species to mean similarity within the group

Table 5 Pairwise analyses of similarity (ANOSIM) of vascular plant communities near to (i.e., 0–2 m) and far from (i.e., 9–15 m) the stream at disconnected and restored sites

	Disconnected near	Disconnected far	Restored near	Restored far
Disconnected near				
Global <i>R</i>		0.126	0.104	0.491
<i>P</i>		0.027*	0.039*	0.001*
Disconnected far				
Global <i>R</i>	0.126		0.062	0.187
<i>P</i>	0.027*		0.117	0.009*
Restored near				
Global <i>R</i>	0.104	0.062		0.065
<i>P</i>	0.039*	0.117		0.103
Restored far				
Global <i>R</i>	0.491	0.187	0.065	
<i>P</i>	0.001*	0.009*	0.103	

* Significant dissimilarities ($\alpha = 0.05$) between groups

construction and subsequent restoration: In the years since floatway structures were installed, reductions in water level and discharge allowed the upland pine forest to expand downwards toward the stream at disconnected sites. Restoration has increased flow levels and caused the active channel to expand back into areas that had been colonized by upland plants when water levels were low. Consequently, areas closest to the stream at restored sites are now occupied by upland communities.

Contrary to our hypothesis, the restored fluvial regime in reconnected side channels appears not to have promoted the development of typically diverse, flood-adapted riparian plant communities. This may be due to the relatively short time interval (ca. 5 years) since restoration. Previous studies have demonstrated that restoring natural patterns of fluvial disturbance can induce relatively quick (3–10 years) responses in riparian plant communities at single-channel tributaries (Helfield and others 2007). It is possible that secondary channels do not respond as quickly because of the more buffered hydrologic regimes typically seen in anabranching or braided systems. Secondary channels typically provide such important refuge habitat for juvenile fishes because they are subject to less frequent and less intense high flow events (e.g., Brown and Hartman 1988). This entails less frequent and less extensive scouring and erosion, with a corresponding lack of bare substrates open to colonization by a diverse riparian flora. It is also likely that most water-dispersed plant propagules stay in the main channel and do not find their way into secondary channels. Consequently, shifts in riparian species composition and increases in diversity might develop over longer periods of time at reconnected channels.

The prevalence of rocky soils in the Pite system is another factor that might slow rates of recovery at these sites. In comparison with the Ume River, where post-restoration recovery has been observed to be faster (Helfield and others 2007), the Pite valley features a lack of fine soil deposits (Wistrand and Lundqvist 1964; Elfström 1988). This contrast in soil characteristics is due to differences in

Table 6 Results of similarity percentage (SIMPER) analyses characterizing species composition of bryophyte communities in quadrats near to (i.e., 0–2 m) and far from (i.e., 9–15 m) the stream at disconnected and restored sites

Group	Disconnected sites			Restored sites		
	Similarity	Characteristic spp.	%	Similarity	Characteristic spp.	%
Near	13.72	<i>Hylocomium splendens</i>	9.79	26.68	<i>Pleurozium schreberi</i>	34.79
		<i>Campyllum stellatum</i>	8.99		<i>Hylocomium splendens</i>	30.72
		<i>Pleurozium schreberi</i>	8.02			
		<i>Campyllum protensum</i>	7.18			
		<i>Sanionica uncinata</i>	7.17			
		<i>Sphagnum warnstorffii</i>	5.79			
		<i>Calliergon cordifolium</i>	4.18			
Far	22.16	Cumulative	51.10	53.44	Cumulative	65.51
		<i>Pleurozium schreberi</i>	38.15		<i>Hylocomium splendens</i>	58.39
		<i>Hylocomium splendens</i>	30.82		<i>Pleurozium schreberi</i>	35.44
		Cumulative	68.97		Cumulative	93.83
Total	7.73	<i>Hylocomium splendens</i>	20.78	22.09	<i>Hylocomium splendens</i>	49.58
		<i>Pleurozium schreberi</i>	18.12		<i>Pleurozium schreberi</i>	37.11
		<i>Sanionica uncinata</i>	15.44			
		Cumulative	54.33		Cumulative	86.70

Similarity values are mean Bray–Curtis similarity among quadrats within each group. Characteristic species are species accounting for >50%, cumulatively, of mean similarity within each group. Percentage (%) values are percent contributions of each species to mean similarity within the group

Table 7 Pairwise analyses of similarity (ANOSIM) of bryophyte communities near to (i.e., 0–2 m) and far from (i.e., 9–15 m) the stream at disconnected and restored sites

	Disconnected near	Disconnected far	Restored near	Restored far
Disconnected near				
Global <i>R</i>		0.279	0.247	0.671
<i>P</i>		0.001*	0.001*	0.001*
Disconnected far				
Global <i>R</i>	0.279		−0.017	0.210
<i>P</i>	0.001*		0.604	0.001*
Restored near				
Global <i>R</i>	0.247	−0.017		0.222
<i>P</i>	0.001*	0.604		0.001*
Restored far				
Global <i>R</i>	0.671	0.210	0.222	
<i>P</i>	0.001*	0.001*	0.001*	

* Significant dissimilarities ($\alpha = 0.05$) between groups

the Quaternary glacial histories of the two catchments (see Nilsson 1979; Sundborg and others 1980). In the absence of fine soils suitable for colonization, establishment of riparian plant communities may take decades. The persistence of bare soil at disconnected sites (Table 4) and the fact that bankfull widths were not significantly narrower at disconnected sites relative to restored sites (Table 1) might therefore reflect a lack of colonizing vegetation in de-watered streambeds due to the inhospitable nature of Pite substrates.

Alternatively, it is possible that channel widths and bare soil are maintained in some disconnected channels by intermittent high flow events that overwhelm floatway

barriers. Where de-watered channels are subject to intermittent floods or spates, fluvial disturbance regimes may be more variable than in restored or even unimpacted channels. To the extent that such variable flow regimes create heterogeneous habitats, limit competitive exclusion by dominants and deposit fine sediments suitable for colonization by opportunistic species, restoration might therefore result in long-term reductions in riparian diversity.

Our observations that bryophyte evenness and H' decrease with distance from the stream (Fig. 4b; Table 4) point to the importance of fluvial processes in influencing riparian diversity. Nonetheless it should be recognized that diversity is not always positively correlated with disturbance frequency (see Mackey and Currie 2001; Li and others 2004). For example, in areas where invasive plants are prevalent, increases in fluvial disturbance frequency might create open patches facilitating colonization by invasive species (Hood and Naiman 2000; Tabacchi and others 2005), resulting in potentially lasting reductions in diversity (Coblentz 1990). Alternatively, in areas where simplified flow regimes favour invasive species (e.g., Howell and Benson 2000; Aguiar and others 2001; Taylor and Ganf 2005), restoring natural flow regimes can be an effective means of controlling invasive species (Stromberg and others 2007). Exotic species are largely absent from floodplain habitats in northern Sweden (Jansson and others 2000; Dynesius and others 2004). Consequently, responses observed in the Pite River are not necessarily applicable to restoration projects in more temperate regions.

Given the disproportionate share of plant species supported by riparian habitats (Naiman and others 1993; Nilsson and Jansson 1995; Goebel and others 2003), restoration strategies aimed at enhancing riparian diversity

may be essential for the preservation or restoration of regional biodiversity. Given the importance of riparian vegetation for salmonid fish habitat (Naiman and Latterell 2005; Lake and others 2007), such strategies may be essential to the success of river restoration efforts. Previous studies have demonstrated that restoring natural flow regimes can enhance the diversity of vascular plant communities in the riparian zones of single-channel tributaries (Helfield and others 2007). The results of this study demonstrate that restoration can have a significant influence on the composition of both vascular plant and bryophyte communities in complex, anabranching systems, but changes in riparian diversity may be slow to develop and not necessarily positive. The difference in response between tributaries and secondary channels is likely due to underlying differences in soil characteristics and fluvial disturbance regimes. In areas with fine sediments suitable for vegetation colonization, restoration practices that result in more variable disturbance regimes are likely to enhance riparian diversity. Conversely, restoration practices that result in less variable disturbance regimes may be more likely to decrease riparian diversity. In regions where invasive species are common and widespread, this relationship may be reversed. These contrasts illustrate how restoration outcomes can vary according to physical and ecological factors as well as the specific nature of degradative influences, reinforcing the need for site-specific restoration plans.

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References

- Aguiar FC, Ferreira MT, Moreira I (2001) Exotic and native vegetation establishment following channelization of a western Iberian river. *Regulated Rivers: Research and Management* 17:509–526
- Andersson E, Nilsson C, Johansson ME (2000) Plant dispersal in boreal rivers and its relation to the diversity of riparian flora. *Journal of Biogeography* 27:1095–1106
- Ångström A (1974) Sveriges Klimat, 3rd edn. Generalstabens Litografiska Anstalts Förlag, Stockholm
- Arthington AH, Naiman RJ, McClain ME, Nilsson C (2010) Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. *Freshwater Biology* 55:1–16
- Auble GT, Scott ML (1998) Fluvial disturbance patches and cottonwood recruitment along the upper Missouri River, Montana. *Wetlands* 18:546–556
- Bagstad JJ, Stromberg JC, Lite SJ (2005) Response of herbaceous riparian plants to rain and flooding on the San Pedro River, Arizona, USA. *Wetlands* 25:210–223
- Beechie TJ, Beamer E, Wasserman L (1994) Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for restoration. *North American Journal of Fisheries Management* 14:797–811
- Bernhardt ES, Palmer MA, Allan JD, Alexander G, Barnas K, Brooks S, Carr J, Clayton S, Dahm C, Follstad-Shah J, Galat D, Gloss S, Goodwin P, Hart D, Hassett B, Jenkinson R, Katz S, Kondolf GM, Lake PS, Lave R, Meyer JL, O'Donnell TK, Pagano L, Powell B, Sudduth E (2005) Synthesizing U.S. river restoration efforts. *Science* 308:636–637
- Boedeltje G, Bakker JP, Brinke AT, Van Groenendael JM, Soesbergen M (2004) Dispersal phenology of hydrochorous plants in relation to discharge, seed release time and buoyancy of seeds: the flood pulse concept supported. *Journal of Ecology* 92: 786–796
- Brown TG, Hartman GF (1988) Contribution of seasonally flooded lands and minor tributaries to the production of coho salmon in Carnation Creek, British Columbia. *Transactions of the American Fisheries Society* 117:546–551
- Cato J (1985) The definitive connection of the Swedish geochronological time scale with the present, and the new data of the zero year in Dövíken, northern Sweden. *Boreas* 14:117–122
- Cellot B (1996) Influence of side-arms on aquatic macroinvertebrate drift in the main channel of a large river. *Freshwater Biology* 35:149–164
- Coblentz BE (1990) Exotic organisms: a dilemma for conservation biology. *Conservation Biology* 4:261–265
- Dynessius M, Jansson R, Johansson ME, Nilsson C (2004) Intercontinental similarities in riparian-plant diversity and sensitivity to river regulation. *Ecological Applications* 14:173–191
- Eckblad JW, Volden CS, Weilgart LS (1984) Allochthonous drift from backwaters to the main channel of the Mississippi River. *American Midland Naturalist* 111:16–22
- Elfström Å (1988) Late glacial hydrology of the upper Pite River valley, Swedish Lapland. *Geografiska Annaler: Series A, Physical Geography* 70:99–123
- Fremstad E (1976) Vegetasjon og flora i rike lov skogslie i Orkladalen, Sor-Trondelag. Ph.D. thesis, University of Bergen, Bergen, Norway
- Fremstad E (1978) *Campylyum protensum* (Brid.) Kindb. in Norway. *Lindbergia* 4:333–336
- Fromm E (1985) Chronological calculation of the varve zero in Sweden. *Boreas* 14:123–125
- Goebel PC, Palik BJ, Pregitzer KS (2003) Plant diversity contributions of riparian areas in watersheds of the Northern Lake States, USA. *Ecological Applications* 13:1595–1609
- Gurnell A, Thompson K, Goodson J, Moggridge H (2008) Propagule deposition along river margins: linking hydrology and ecology. *Journal of Ecology* 96:553–565
- Hallingbäck T (1996) *Ekologisk katalog över mossor*. Swedish Species Information Centre, Swedish University of Agricultural Sciences (SLU), Uppsala
- Helfield JM, Capon SJ, Nilsson C, Jansson R, Palm D (2007) Restoration of rivers used for timber floating: effects on riparian plant diversity. *Ecological Applications* 17:840–851
- Hood WG, Naiman RJ (2000) Vulnerability of riparian zones to invasion by exotic vascular plants. *Plant Ecology* 148:105–114
- Howell J, Benson D (2000) Predicting potential impacts of environmental flows on weedy riparian vegetation of the Hawkesbury-Nepean River, south-eastern Australia. *Austral Ecology* 25:463–475
- Hylander K, Dynessius M (2006) Causes of the large variation in bryophyte species richness and composition among boreal streamside forests. *Journal of Vegetation Science* 17:333–346

- Hylander K, Jonsson BG, Nilsson C (2002) Evaluating buffer strips along boreal streams using bryophytes as indicators. *Ecological Applications* 12:797–806
- Jansson R, Nilsson C, Dynesius M, Andersson E (2000) Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. *Ecological Applications* 10:203–224
- Jansson R, Zinko U, Merritt DM, Nilsson C (2005) Hydrochory increases riparian plant species richness: a comparison between a free-flowing and a regulated river. *Journal of Ecology* 93:1094–1103
- Jonsson BG (1997) Riparian bryophyte vegetation in the Cascade mountain range, Northwest USA: patterns at different spatial scales. *Canadian Journal of Botany* 75:744–761
- Kimmerer RW, Allen TFH (1982) The role of disturbance in the pattern of a riparian bryophyte community. *American Midland Naturalist* 107:370–383
- Lake PS, Bond N, Reich P (2007) Linking ecological theory with stream restoration. *Freshwater Biology* 52:597–615
- Li J, Loneragan WA, Duggin JA, Grant CD (2004) Issues affecting the measurement of disturbance response patterns in herbaceous vegetation: a test of the intermediate disturbance hypothesis. *Plant Ecology* 172:11–26
- Lundqvist M (1953) Atlas över Sverige. Svenska Sällskapet för Antropologi och Geografi, Stockholm
- Mackey RL, Currie DJ (2001) The diversity–disturbance relationship: is it generally strong and peaked? *Ecology* 82:3479–3492
- Mossberg B, Stenberg L (2003) Den Nya Nordiska Floran. Wahlström & Widstrand, Stockholm
- Muotka T, Laasonen P (2002) Ecosystems recovery in restored headwater streams: the role of enhanced leaf retention. *Journal of Applied Ecology* 39:145–156
- Muotka T, Paavola R, Haapala A, Novikmec M, Laasonen P (2002) Long-term recovery of stream habitat structure and benthic invertebrate communities from in-stream restoration. *Biological Conservation* 105:243–253
- Naiman RJ, Décamps H (1997) The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics* 28:621–658
- Naiman RJ, Latterell JJ (2005) Principles for linking fish habitat to fisheries management and conservation. *Journal of Fish Biology* 67:166–185
- Naiman RJ, Décamps H, Pollock MM (1993) The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3:209–212
- Naiman RJ, Featherston KL, McKay SJ, Chen J (1998) Riparian forests. In: Naiman RJ, Bilby RE (eds) *River ecology and management*. Springer, New York, pp 289–323
- Nilsson C (1979) Piteälven, Laisälven och Vindelälven. Växt- och djurliv samt biologiska effekter av vattenöverledning. *Wahlebergia* 6:1–59
- Nilsson C (1983) Frequency distributions of vascular plants in the geolittoral vegetation along two rivers in northern Sweden. *Journal of Biogeography* 10:351–369
- Nilsson C (1986) Change in riparian plant community composition along two rivers in northern Sweden. *Canadian Journal of Botany* 64:589–592
- Nilsson C (1999) Rivers and streams. *Acta Phytogeographica Suecica* 84:135–148
- Nilsson C, Grelsson G (1990) The effects of litter displacement on riverbank vegetation. *Canadian Journal of Botany* 68:735–741
- Nilsson C, Jansson R (1995) Floristic differences between riparian corridors of regulated and free-flowing boreal rivers. *Regulated Rivers: Research & Management* 11:55–66
- Nilsson C, Gardfjell M, Grelsson G (1991) Importance of hydrochory in structuring plant communities along rivers. *Canadian Journal of Botany* 69:2631–2633
- Nilsson C, Ekblad A, Dynesius M, Backe S, Gardfjell M, Carlberg B, Hellqvist S, Jansson R (1994) A comparison of species richness and traits of riparian plants between a main channel and its tributaries. *Journal of Ecology* 82:281–295
- Nilsson C, Xiong S, Johansson ME, Vought LB-M (1999) Effects of leaf litter accumulation on riparian plant diversity across Europe. *Ecology* 80:1770–1775
- Nilsson C, Andersson E, Merritt DM, Johansson ME (2002) Differences in riparian flora between riverbanks and river lakeshores explained by dispersal traits. *Ecology* 83:2878–2887
- Nilsson C, Lepori F, Malmqvist B, Hjerdt N, Helfield JM, Palm D, Östergren J, Jansson R, Brännäs E, Lundqvist H (2005) Forecasting environmental responses to restoration of rivers used as log floatways: an interdisciplinary challenge. *Ecosystems* 8:779–800
- Nilsson C, Brown RL, Jansson R, Merritt DM (2010) The role of hydrochory in structuring riparian and wetland vegetation. *Biological Reviews* 85:837–858
- Palmer MA, Bernhardt ES, Allan JD, Lake PS, Alexander G, Brooks S, Carr J, Clayton S, Dahm CN, Follstad-Shah J, Galat DL, Loss SG, Goodwin P, Hart DD, Hassett B, Jenkinson R, Kondolf GM, Lave R, Meyer JL (2005) Standards for ecologically successful river restoration. *Journal of Applied Ecology* 42:208–217
- Pharo EJ, Beattie AJ (1997) Bryophyte and lichen diversity: a comparative study. *Australian Journal of Ecology* 22:151–162
- Poff NL, Allan JD, Bain MB, Karr JR, Prestegard KL, Richter BD, Sparks RE, Stromberg JC (1997) The natural flow regime: a new paradigm for riverine conservation and restoration. *BioScience* 47:769–784
- Pollock MM, Naiman RJ, Hanley TA (1998) Plant species richness in riparian wetlands: a test of biodiversity theory. *Ecology* 79:94–105
- Proctor MCF (1990) The physiological basis of bryophyte production. *Botanical Journal of the Linnean Society* 104:61–77
- Roni P, Beechie TJ, Bilby RE, Leonetti FE, Pollock MM, Pess GR (2002) A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. *North American Journal of Fisheries Management* 22:1–20
- Schropp MHI, Bakker C (1998) Secondary channels as a basis for the ecological rehabilitation of Dutch rivers. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8:53–59
- Seegrist DW, Gard R (1972) Effects of floods on trout in Sagehen Creek, California. *Transactions of the American Fisheries Society* 101:478–482
- Shannon CE, Weaver W (1949) *The mathematical theory of communication*. University of Illinois Press, Urbana
- Sheaffer WA, Nickum JG (1986a) Relative abundance of macroinvertebrates associated with backwater area confluences in Pool 13 of the Upper Mississippi River. *Hydrobiologia* 136:113–120
- Sheaffer WA, Nickum JG (1986b) Backwater areas as nursery habitats for fishes in Pool 13 of the Upper Mississippi River. *Hydrobiologia* 136:131–140
- Stromberg JC, Lite SJ, Marler R, Paradzick C, Shafroth PB, Shorrock D, White JM, White MS (2007) Altered stream-flow regimes and invasive plant species: the *Tamarix* case. *Global Ecology and Biogeography* 16:381–393
- Sundborg Å, Elfström Å, Rudberg S (1980) Piteälven, Laisälven och Vindelälven. Naturförhållanden och miljöeffekter vid vattenöverledning. UNGI Rapport 51. Department of Physical Geography, Uppsala University, Uppsala
- Tabacchi E, Planty-Tabacchi AM, Roques L, Nadal E (2005) Seed inputs in riparian zones: implications for plant invasion. *River Research and Applications* 21:299–313
- Taylor B, Ganf GG (2005) Comparative ecology of two co-occurring floodplain plants: the native *Sporobolus mitchellii* and the exotic *Phyla canescens*. *Marine and Freshwater Research* 56:431–440
- Tockner K, Stanford JA (2002) Riverine flood plains: present state and future trends. *Environmental Conservation* 29:308–330

- Törlund E (2002) Flottningen dör aldrig: bäckflottningens avveckling efter Ume- och Vindelälven 1945–70. Ph.D. dissertation, Umeå University, Umeå, Sweden
- Törlund E, Östlund L (2002) Floating timber in northern Sweden: the construction of floatways and transformation of rivers. *Environment and History* 8:85–106
- Tschaplinski PJ, Hartman GF (1983) Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. *Canadian Journal of Fisheries and Aquatic Sciences* 40:452–461
- Vogt K, Rasran L, Jensen K (2006) Seed deposition in drift lines during an extreme flooding event: evidence for hydrochorous dispersal? *Basic and Applied Ecology* 7:422–432
- Ward JV, Tockner K, Schiemer F (1999) Biodiversity of floodplain river ecosystems: ecotones and connectivity. *Regulated Rivers: Research and Management* 15:125–139
- Ward JV, Tockner K, Arscott DB, Claret C (2002) Riverine landscape diversity. *Freshwater Biology* 47:517–539
- Wistrand G, Lundqvist J (1964) Kärlväxtflora på och kring Stränderna inom Mellersta Piteälvens Vattensystem. Almqvist & Wiksells Boktryckeri AB, Uppsala