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Response of herbaceous plant community diversity and composition to overstorey harvest within riparian management zones in Northern Hardwoods

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Partial timber harvest within riparian management zones (RMZs) may permit active management of riparian forests while protecting stream ecosystems, but impacts on herbaceous communities are poorly understood. We compared herbaceous plant community abundance, diversity and composition in RMZs along small streams in northern Minnesota, USA, among four treatments before harvest and 1 year and 9 years following treatment. Treatments included a no-harvesting control and three different treatments of the RMZs where the adjacent upland forest was clearcut: (1) an RMZ control, with no harvesting in the RMZ; (2) RMZ TL, in which the RMZ was partially harvested (60 per cent removal of basal area) using tree-length harvesting and (3) RMZ cut-to-length (CTL), in which the RMZ was partially cut (also 60 per cent removal) using CTL harvesting. Herbaceous cover, richness, diversity and most synecological coordinate scores (reflecting tolerances for light, heat, moisture and nutrients) varied over time but not among riparian treatments, whereas composition varied over time and by treatment but not differentially among treatments over time. These results indicate a lack of herbaceous plant community response to partial timber harvesting within these RMZs, which is consistent with previous work suggesting that understorey communities may be resistant to change below thresholds of disturbance intensity.

Introduction

Forested riparian areas are vital to protecting terrestrial and aquatic ecosystems.[1–3] Primarily because of the critical role of streamside overstorey structure and composition in maintaining stream temperature, bank stabilization, filtering of nutrients and organic matter input into the stream[3–5] timber harvest is often restricted within riparian buffers[6] or riparian management zones (RMZs)[7] to limit changes to sedimentation, soil nutrients and aquatic biota.[8,9]

Uncut riparian buffers ameliorate impacts of timber harvesting on abiotic and biotic stream conditions.[10–12] Although successful in providing stream protection, uncut buffer strips impede the restoration of, and management for, diverse riparian areas on the landscape,[13,14] necessitate forgoing active timber management opportunities[15] and prevent financial gain from timber sales.[16,17] In contrast, active management in riparian areas (i.e. partial timber harvesting that retains residual vegetation after harvest) has also been found to lessen harvesting effects on stream conditions while providing adequate protection of water quality.[18–20]

Riparian areas can also be especially important repositories of plant biodiversity.[1,21] Herbaceous plant communities in particular are known to be quite sensitive to forest management in upland ecosystems,[22–24] where timber harvesting can change community composition and abundance.[25–27] Herbaceous communities in riparian areas may be similarly sensitive, but there have been few studies to quantify this, particularly in boreal and near boreal forests. Managed riparian forests have been found to have significantly higher average light levels compared with their unmanaged counterparts, resulting in increases in shade-intolerant species in the understorey, particularly near the edge of the stream[28]. The biomass of understorey vegetation has also been found to be greater in partially harvested RMZs than in uncut zones in the year following treatment.[29] The effectiveness of RMZs for maintaining riparian herbaceous communities, therefore, depends on the response of these communities to varying harvest levels. Because herbaceous plants are drivers of ecosystem functions such as nutrient cycling,[30] their response may further reflect the degree of alteration in riparian functions that result from harvesting.

If riparian herbaceous communities are highly sensitive to overstorey management, timber production in the RMZ may come at the cost of herbaceous biodiversity. If, however, these communities are either resistant to harvest, showing little change following harvest, or resilient, eventually resuming pre-harvest compositional conditions, it may be possible to actively manage riparian forests for a variety of objectives. The objective of the current study, therefore, was to evaluate the impacts of three levels of management activity (no harvest and partial cut-to-length (CTL) harvest and whole-tree harvest) on herbaceous plant community diversity and composition within RMZs. This examination is important in that it addressed the sustainability of native plant community diversity in managed riparian areas, but also because such changes, or the lack thereof, may be reflective of the impacts of management on riparian ecosystem functions.

Methods

Site description

The study area included four first-order streams draining into Pokegama Lake (47°11′8″N, 93°34′29″W) in an area of Minnesota with annual precipitation of 61–69 cm, 40 per cent of which occurs during the summer growing season. Average temperature is −10.6°C in winter and 16.7°C in summer.[31] Well-drained to somewhat poorly drained calcareous soils on an end-moraine support Northern Rich Mesic Hardwood Forest.[32] The study was conducted in 70- to 120-year-old second-growth forest; dominant tree species at the start of the study were trembling aspen (*Populus tremuloides* Michx., 13–24 per cent relative basal area (RBA)), paper birch (*Betula papyrifera* Marsh., 10–19 per cent RBA), sugar maple (*Acer saccharum* Marsh.; 8–22 per cent RBA) and basswood (*Tilia Americana* L.; 1–15 per cent RBA). Northern white-cedar (*Thuja occidentalis* L.) and black ash (*Fraxinus nigra* Marsh.) were abundant along the stream edges. Nomenclature follows the USDA PLANTS database.

Experimental design

The 12 experimental units were established in 1996 across north–south oriented stream reaches. Units were 135–200 m long and at least 100 m apart when on the same stream such that each ca. ∼4.8 ha unit extended from the upland forest on the eastern-facing slope above a stream through the riparian forest along the stream, across the stream, through the opposite riparian forest, and up toward the upland forest on the western-facing slope (Figure 1). In each unit, the RMZ was designated as the area extending 30.5 m from the centre of the stream into the forest on both sides of the stream. A slight gradient of topographic features (fluvial landforms) extended from the stream through the RMZ and into the upland forest.

The completely randomized design involved applying four harvesting treatments randomly assigned to each of three replicate stands in the late summer to early fall of 1997.[33] The four treatments included (1) full control (FC, with no harvesting in either the RMZs or upland forests); (2) RMZ control (RMZC, no harvesting in the RMZs and clearcutting of the upland forests); (3) RMZ TL (TL, traditional tree-length harvesting in the RMZs and clearcutting of the upland forests) and (4) RMZ cut-to-length (CTL, harvesting in the RMZs and clearcutting of the upland forests). Both RMZ TL and RMZ CTL treatments were partially harvested (cut trees were ≥10 cm diameter at breast (1.37 m) height (DBH)) to a residual basal area of ∼13 m^2 ha^{-1} (60 per cent removal). There was a gradient of harvesting intensity in the RMZ portion of the stands from low- to high-intensity removal of overstorey trees from stream to clearcut edge, with no trees harvested within 5 m of the stream. In addition, blowdown occurred over the 9-year post-treatment period, further reducing overstorey density by 30 and 50 per cent of the first-year post-treatment density in the RMZC and the partially harvested treatments, respectively.[34]

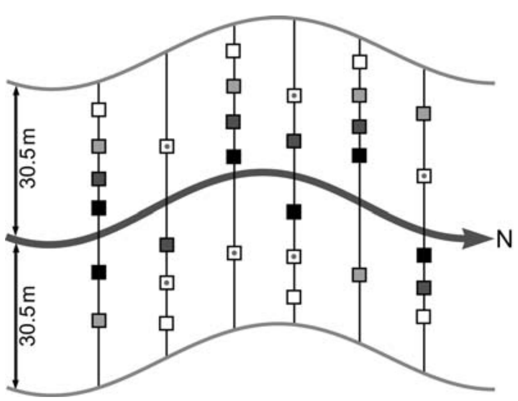

Figure 1 Within the RMZ at each site, five to eight transects were extended 30.5 m out on either side of the stream. Plots were placed along each transect to occur entirely within one of the five fluvial landforms when present: floodplain (black), stream-side slope (dark grey), midslope terrace (white with centre dot), upland-side slope (light grey) and upland-side terrace (white).

Sampling

In each unit, five to eight equal-length transects were established perpendicular to the stream (Figure 1) and, on each transect, three to six permanent plots were placed in each of the fluvial landforms (floodplain, slope or terrace) on both sides of the stream. Transects initiated at different distances from the upland edge and crossed the stream, creating a 'short side' of the transect with one to two plots on one side of the stream and a 'long side' with two to four plots on the opposite side. Short and long sides usually alternated along the stream reach moving from north to south. Because plots were placed in different fluvial landforms, distances between plots varied according to inherent variation in topography.

Herbaceous vegetation was sampled in 1997 (pre-harvest), 1998 (1-year post-harvest) and 2006 (9 years post-harvest) within 0.5-m^2 square subplots that were offset (to the north or south) by 1 m from the permanent plot centre following the methods of Goebel *et al.*[18] Individuals were identified to species (or occasionally to genus or family when identification was uncertain) and per cent cover was estimated using cover classes (1 = trace–1 per cent; 2 = 1–5 per cent; 3 = 5–15 per cent; 4 = 15–30 per cent; 5 = 30–60 per cent and 6 = 60–100 per cent). Cover classes were later converted to per cent cover using the midpoint of the class range. Total mean per cent herbaceous cover was computed as well as separate estimates for different functional groups (i.e. forbs, graminoids, ferns, horsetails and lycopods, and mosses). To assess whether herb abundance changed differently in plots close to the stream edge and plots close to the clearcut edge, total herbaceous cover was also computed separately for subplots located (1) within 10 m of the stream and (2) within 10 m of the clearcut edge. In addition, synecological coordinates for light (L), heat (H), moisture (M) and nutrients (N) were obtained for each species,[35] in which 1 = low prevalence and 5 = high prevalence of occurrence when competing with other plants.[36] Mean synecological scores, calculated for each plot based on the synecological coordinates of species present weighted by their relative cover, indicate environmental requirements of plants and are interpreted as relative plant indicator values.[37]

Data analysis

Repeated-measures two-way mixed ANOVA models were used to test whether total cover, species richness, Shannon diversity (calculated in *PC-ORD* v. 6)[38] and the four synecological scores were affected by treatment, time and the treatment × time interaction after averaging across plots to the unit level. The repeated and random statements for all tests were time and unit nested in treatment, respectively. Initially, the models were developed at the fluvial landform level (i.e. averaging across plots within fluvial landforms at each site), but because treatment effects did not vary by fluvial landform (all $P > 0.10$), the data were aggregated to the unit level (and thus across landforms). A covariance structure appropriate for unequal lengths of time between sampling periods and with the lowest Akaike Information Criterion value was chosen for the analysis. Degrees of freedom were calculated using the Satterthwaite method.[39,40] Under Fisher's Protected Least Significant Difference (LSD), a subset of pairwise comparisons of differences of least-squared means was examined to directly address how a particular treatment changed over time and how treatments differed within a particular time period. A Bonferroni correction was used to assess time and treatment differences at the overall $\alpha = 0.10$ level. All univariate analyses were performed in SAS 9.1 (SAS Institute).

Variation in herbaceous species composition among treatments and across time was explored using multivariate analyses on cover class midpoint abundance averages for four treatments × three replicates × three times. Species were retained if they occurred in at least three of the 36 observations, resulting in a matrix of the relativized (by species maxima) average cover-class midpoints of 87 species across 36 observations. Differences in species composition were evaluated using a two-way factorial distance-based MANOVA procedure with treatment and time as factors (PerMANOVA in *PC-ORD*) based on the Sørensen distance measure. Patterns of community response in herbaceous vegetation with treatment and time were evaluated by examining the shift in species composition reflected in nonmetric multidimensional scaling (NMS in *PC-ORD*) ordination, using the Sørensen distance measure. Multiple NMS solutions using 250 runs with both the real and the randomized data were evaluated to determine optimal dimensionality and consistency of interpretation. A unique ($P < 0.01$) three-dimensional solution with final stress of 15 is reported. To facilitate interpretation, the ordination was rotated to express the variation associated with time since harvest on the first (horizontal) axis. The most influential species were determined by associating (using the Pearson correlation coefficient) their abundance values with each ordination axis; only species with $r > 0.4$ are reported. Indicator species analysis in *PC-ORD* was also used to determine which species were most constant and abundant in each treatment after blocking by time, based on a difference in IV of at least 20 points among groups at the $\alpha = 0.10$ level.

The amount of compositional change over time was contrasted among treatments using vector lengths calculated from the NMS ordination scores (i.e. the distance between time periods in ordination space based on the Pythagorean Theorem). Vector lengths were calculated using all axes of the ordination solution to obtain the distances between each time period and the succeeding time period as well as between pre-harvest and year 9 after harvest. A one-way ANOVA was used to evaluate if vector lengths between the time periods differed among treatments. Under a protected LSD of the overall model for each distance, pre-determined contrasts were constructed to compare treatments in the following way: (1) FC *vs* RMZC for the effect of a clearcut edge in unharvested RMZs; (2) CTL *vs* TL for comparing harvesting methods; (3) RMZC *vs* CTL + TL for comparing the effect of partial harvests in RMZs; and (4) FC *vs* CTL + TL for testing the combined effects of the clearcut edge and partial harvest in the RMZ. The hypothesis testing for these multiple comparisons was controlled using the Bonferroni method with an overall α of 0.10.

Table 1 *P*-values for univariate herbaceous community responses compared among treatments (Trt) and over time using repeated measures analysis

	Trt	Time	Time × Trt
Total cover	ns	0.01	0.08
Species richness	ns	<0.001	<0.001
Species diversity	ns	<0.001	ns
Moisture score	ns	0.05	ns
Light score	ns	ns	ns
Nutrient score	ns	0.02	ns
Heat score	ns	0.02	ns

Significance was evaluated at the $\alpha = 0.10$ level.

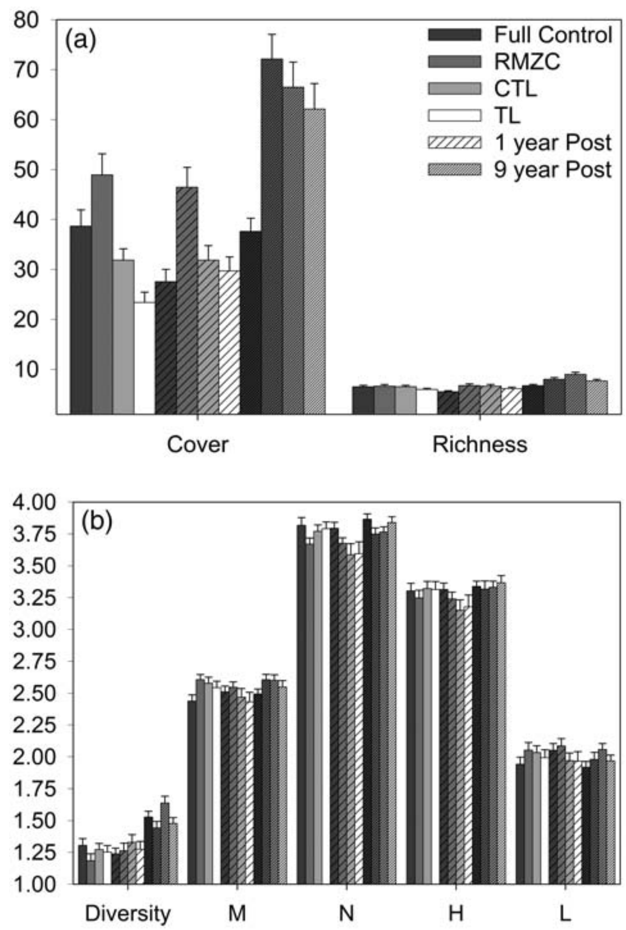

Figure 2 Mean (bars = one standard error) univariate herbaceous responses (cover, species richness, species diversity and synecological scores for moisture (M), nutrients (N), heat (H) and light (L)) across treatments and over time. There were no significant differences among treatments (differentiated by shading) for any response in any time period (differentiated by cross-hatches). The probabilities of type II errors (i.e. failing to reject the null hypothesis of no treatment differences when the null hypothesis is false) to detect a 10 per cent treatment difference were 0.72 for total cover, 0.33 for species richness, 0.26 for species diversity, 0.00 for synecological scores for M, N and H, and 0.05 for L.

Results

Abundances and diversity

Repeated-measures analyses demonstrated that there were no statistically significant riparian treatment effects on sites where the upland had been clearcut. The observed statistically significant differences among treatments in change over time (ANOVA, Table 1) merely reflected an increase between years 1 and 9 in herbaceous cover and richness in all treatments (all $P < 0.08$) except the FC, resulting in significant differences in cover between the FC and both the RMZC ($P = 0.047$) and the CTL ($P = 0.067$) by year 9; no significant differences were ever observed between the riparian control and either of the riparian cut treatments. Similarly, species richness increased significantly species richness increased significantly between years 1 and 9 in all treatments ($P < 0.001$) except the FC, but no significant differences were ever observed between the riparian control and either of the riparian cut treatments. No statistically significant treatment effects were observed for species diversity or any of the synecological scores that were calculated across all species (ANOVA, all $P > 0.3$, Table 1, Figure 2). Although per cent cover of most functional groups increased over time in the RMZC, CTL and TL treatments, there were also no significant differences among treatment combinations over time by functional group (Table 2). Similarly, no significant differences were observed for per cent cover by treatment over time in plots that were within 10 m of the stream or within 10 m of the clearcut edge. Of the full 130 species, indicator species analysis identified only 12 species as more constant and abundant in one treatment over another when controlling for the effects of time: two (*Caulophyllum thalictroides* (L.) Michx. and *Hepatica americana* (DC.) Ker Gaw) in the FC, five (*Amphicarpaea bracteata* (L.) Fern., *Aster* spp., *Equisetum* spp., *Osmunda claytoniana* L., *Phegopteris connectilis* (Michx.) Watt) in the RMZC and five (*Adiantum pedatum* L., *Athyrium filix-femina*, *Lycopodium dendroideum* Michx., *Lycopodium lucidula* Michx., *Viola pubescens* Ait.) in the CTL.

Table 2 Mean per cent cover (standard error) of herbaceous vegetation functional groups in each treatment through time (years)

	Full control	RMZ control	RMZ CTL	RMZ TL
Ferns				
Pre-harvest	9.2 (4.7)	16.0 (4.7)	5.7 (4.7)	8.5 (4.7)
1 post-harvest	8.0 (4.4)	16.5 (4.4)	5.0 (4.4)	6.3 (4.4)
9 post-harvest	4.7 (7.4)	25.8 (7.4)	13.4 (7.4)	20.2 (7.4)
Forbs				
Pre-harvest	22.6 (5.3)	21.1 (5.3)	14.2 (5.3)	16.3 (5.3)
1 post-harvest	14.8 (3.2)	22.9 (3.2)	17.8 (3.2)	15.7 (3.2)
9 post-harvest	26.1 (6.8)	29.9 (6.8)	41.2 (6.8)	34.6 (6.8)
Graminoids				
Pre-harvest	3.7 (1.9)	5.0 (1.9)	2.4 (1.9)	2.6 (1.9)
1 post-harvest	2.9 (2.1)	4.7 (2.1)	5.9 (2.1)	4.5 (2.1)
9 post-harvest	5.4 (3.9)	11.4 (3.9)	7.3 (3.9)	7.7 (3.9)
Horsetails/lycopods				
Pre-harvest	1.0 (0.4)	1.2 (0.4)	0.6 (0.4)	1.0 (0.4)
1 post-harvest	1.2 (0.7)	1.4 (0.7)	0.9 (0.7)	1.9 (0.7)
9 post-harvest	1.1 (0.9)	3.0 (0.9)	0.8 (0.9)	2.3 (0.9)
Mosses				
Pre-harvest	2.9 (1.6)	6.6 (1.6)	1.5 (1.6)	4.4 (1.6)
1 post-harvest	1.8 (1.1)	5.6 (1.1)	1.1 (1.1)	3.3 (1.1)
9 post-harvest	2.0 (2.2)	7.8 (2.2)	3.5 (2.2)	5.7 (2.2)

Species composition

Species composition in the herbaceous layer did vary significantly over time (PerMANOVA, $P = 0.005$) and by treatment ($P = 0.008$), but not differently by treatment over time. These patterns were weakly evident in the NMS ordination diagram, which reflected compositional changes associated with time on Axis

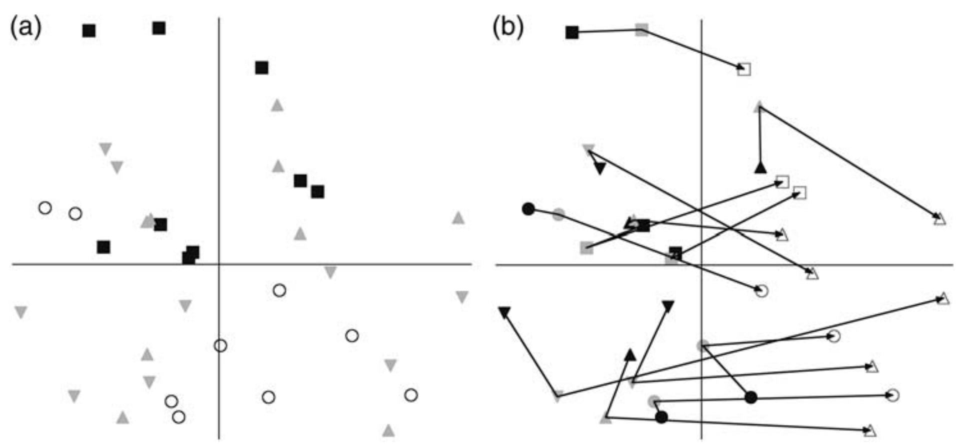

Figure 3 NMS ordination diagram of the herbaceous layer, showing Axis 1 (19 per cent, horizontal) and Axis 2 (24 per cent, vertical): each point represents a unit at one of the three time periods. (a) The vertical axis (2) shows compositional segregation of the FC (black square, in the upper quadrants) from the RMZC (open circle, mostly in the lower quadrants) and an intermingling of the CTL (grey triangle) and TL (grey inverted triangle) with both controls. (b) The horizontal axis (1) shows very consistent shifts in composition over time (from black to grey to white symbols) among all treatments, although the magnitude of change (i.e. vector length) appears slightly less for the FC (squares) and RMZC (circles) than for either of the cut treatments (triangles).

Table 3 Herbaceous layer species associated with the NMS ordination axes (Pearson correlation coefficients $r > 0.4$ shown)

Species	Axis 1 (19%)	Axis 2 (24%)	Axis 3 (36%)
Amphicarpaea bracteata (L.) Fern.			−0.43
Aralia nudicaulis L.			−0.62
Arisaema triphyllum (L.) Schott	0.54		
Asarum canadense L.			−0.56
Aster macrophyllus L.	0.47	−0.67	−0.49
Athyrium filix-femina (L.) Roth.		−0.64	−0.43
Botrychium virginianum L.			−0.59
Carex pensylvanica Lam.		−0.59	
Carex spp.	0.49		−0.45
Circaea lutetiana L.			0.44
Clintonia borealis (Aiton.) Raf.		−0.42	
Calystegia sepium (L.) R. Br./*Polygonum cilinode* Michx.	0.61		
Equisetum fluviatile L.	−0.41		
Fragaria virginiana Duchesne.			−0.45
Gallium asperellum Michx. and *G. triflorum* Michx.	0.67		−0.43
Grasses	0.65		−0.47
Gymnocarpium dryopteris (L.) Newman			−0.41
Hepatica americana (DC.) Ker Gaw.			−0.41
Laportea canadensis (L.) Wedd.			0.57
Lathyrus spp.	0.57		−0.4
Maianthemum canadense Desf.			−0.54
Matteuccia struthiopteris (L.) Todaro	0.5	−0.49	
Mitella nuda L.	0.52		
Oryzopsis asperifolia Michx.			−0.56
Osmorhiza claytonia (Michx.) C.D. Clark			−0.63
Phegopteris connectilis (Michx.) Watt	0.44		−0.4
Polygonatum biflorum (Willd.) Pursh./*Uvularia sessilifolia* L.			−0.46
Pteridium aquilinum (L.) Kuhn			−0.45
Pyrola elliptica Nutt.			−0.61
Ranunculus recurvatus Poir.	0.55		
Rubus pubescens Raf.	0.42	−0.49	−0.58
Sanguinaria canadensis L.			−0.4
Sanicula marilandica L.			−0.45
Streptopus roseus (L.) DC			−0.51
Symphyotrichum cordifolium (L.) G.L. Nesom	0.51		
Taraxacum officinale F.H. Wigg.	0.58		−0.41
Viola spp.	0.65		−0.42

Axis 1 was rotated to reflect the trend in variation associated with time.

1 (19 per cent of the variation in the distance matrix), treatment on Axis 2 (24 per cent) and neither time nor treatment on Axis 3 (36 per cent) (Figure 3). The first axis was influenced by species that increased in abundance over time, such as grasses, bedstraw (*Galium* L.) and violets (*Viola* L.) (Table 3) with the single exception of water horsetail (*Equisetum fluviatile* L.), which became less abundant over time. The second axis contrasted the greater abundance of several species in the RMZC and TL treatments compared with the FC and CTL, such as large-leaved aster (*Aster macrophyllus* (L.) Cass.), ladyfern (*Athyrium filix-femina* (L.) Roth) and Pennsylvania sedge (*Carex pensylvanica* Lam.). The third axis, which explained the majority of the variation (36 per cent) but showed no pattern with either treatment or time, nor the time × treatment interaction, was strongly positively associated with only two species (broadleaf enchanter's nightshade (*Circaea lutetiana* L.) and Canadian woodnettle (*Laportea Canadensis* (L.) Weddell)) but negatively associated with many other species (Table 3). This axis showed fairly strong compositional segregation on the basis of geographic unit (i.e. stream segments).

There were no significant differences among treatments in the cumulative composition of the herbaceous community (i.e. NMS vectors, Figure 3b) between the FC and RMZC, between the CTL and TL or between the FC or RMZC and the combined cut treatments. The only significant difference observed was between TL and the FC and only for 1 year post-treatment (ANOVA, $P = 0.02$).

Discussion

Despite concern over the impacts of partial timber harvesting in RMZs, relatively few studies have documented the impacts to understorey communities, particularly in northern forests.[41] In contrast with earlier reports of shifts in biomass[29] and composition,[28,42] the current study did not detect a strong or statistically significant systematic impact of partial riparian harvesting on the RMZ herbaceous understorey community. Although it is possible that the herbaceous community responded more strongly to the treatments during the intervening years (between sampling years 1 and 9), the maintenance (or resumption) of a comparable species composition across treatments by 9 years after treatment indicates that these harvest levels and methods had no greater long-term effect on the herbaceous community than the clearcutting of the adjacent upland areas. Although some species typically indicative of disturbed and high-light environments (e.g. dandelion, wild strawberry, thistle and asters[27,43,44]) were observed in the RMZC as well as the harvested treatments, indicating somewhat altered conditions, it is likely that these few disturbance indicators will decline in abundance with time and further canopy closure.[22,45]

Our results of no statistically significant effect of harvesting in the riparian zone for any univariate response and only a weak and ambiguous treatment separation in the ordination indicate that this herbaceous plant community was resistant to whatever changes in environmental condition may have occurred as a result of the partial timber harvesting within these RMZs. Further, from the lack of change in synecological coordinates, we infer that the environmental conditions of these sites did not in fact change sufficiently to shift the herbaceous community. The lack of a strong response by the herbaceous community may reflect some factors specific to this study (e.g. an initial predominance of generalist species), as well as factors that can be common to timber harvests throughout this region (e.g. low soil disturbance during winter harvest). However, there is some indication that herbaceous vegetation communities may frequently exhibit a certain degree of resistance to change following timber harvesting, including within ≥15-m wide riparian buffers.[46]

Previous work in non-riparian forests has demonstrated few differences in herbaceous vegetation even across more drastic treatments (e.g. clearcuts *vs* gap openings)[47] or a range of basal area removals,[48] and in light of more extensive disturbance (e.g. nearly two-thirds forest floor disturbance).[49] The treatments applied in the riparian zone in this study may thus have been insufficiently intense to induce widespread change in plant community composition and abundance.

Evidence for thresholds of disturbance intensity for understorey vegetation response can be found in studies examining ranges of treatment intensities. For example, understorey trees, shrubs and some herbaceous plants significantly increased in abundance 4 years after harvest only in the two most intense treatments (group selection and clearcutting) and not in less intense treatments (single tree selection and thinning) in mixed oak forests in Missouri, perhaps after reaching a threshold of disturbance.[44] Similarly, plant communities changed with increasing intensity of partial harvesting (between 20 and 75 per cent retention) but explicit changes in species indicators for shade tolerance only occurred in the most extreme treatments in different types of boreal forests in Canada.[50] Plant community composition in the Pacific Northwest was also found to differ between 15 and 40 per cent overstorey retention.[51] After separating partially harvested stands based on low (1–25 per cent BA), medium (26–50 per cent BA) and heavy (>50 per cent BA) harvesting intensity, a study in south-east Alaska found that only the heaviest cutting intensity affected plant composition and abundance.[52]

The apparent resistance of these communities to a 60 per cent overstorey basal area removal indicates that it may be possible to actively manage riparian forests for a variety of objectives without undermining understorey herbaceous biodiversity. Moreover, in the context of herbaceous plant communities as important drivers of ecosystem function,[30] our results suggest riparian area functionality may be sustained under the type and level of riparian disturbance employed in this experiment.

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Conflict of interest statement

None declared.

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