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Regeneration Responses in Partially-Harvested Riparian Management Zones in Northern Minnesota

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Abstract

Trees serve important functions in riparian areas. Guidelines often suggest how riparian forests should be managed to sustain functions, including tree retention and increasing the component of conifers and later-successional species. While regeneration of early successional species is not discouraged, there is uncertainty about the ability to regenerate the latter along with more desirable species. We investigated the regeneration of species differing in successional status and growth forms under different amounts of residual basal area. The study was conducted in riparian sites in northern Minnesota USA. At each site, one portion of the riparian area was uncut, while a downstream area was harvested to 16 or 8 $m^2 \cdot ha^{-1}$. Woody vegetation was sampled before and five-years after harvesting and summarized as early, mid-, and late successional hardwoods, as well as conifers and shrubs. After five years, the density of early successional trees was lower at 16 $m^2 \cdot ha^{-1}$ compared to 8 $m^2 \cdot ha^{-1}$; densities in both treatments were lower than in clearcuts. Densities of mid- and late successional hardwoods and conifers did not increase in either treatment. The higher basal area treatment resulted in a lower density of shrubs, which might be important for establishing more desirable tree species, although this may require additional activities to promote establishment.

Keywords

Riparian Management, Overstory Retention, Regeneration, RMZ, Riparian Forest

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1. Introduction

Trees in riparian areas serve many important ecological functions, including shading of streams, bank stabilization and protection from erosion, interception and uptake of water and nutrients from the upland [1]-[4]. Additionally, riparian trees contribute energy in the form of particulate and dissolved organic matter to aquatic systems [5] and they are the future source of coarse woody debris in streams and lakes [6]. Riparian forests are important habitat for species that are dependent on forests in close proximity to water [7] [8].

Many organizations and agencies have guidelines on how riparian forests should be managed to sustain ecological functions [9] [10]. Typically, these guidelines stress retention of trees in the riparian management zone (RMZ) and provide recommendations about minimum basal areas to be retained during harvesting. Also, guidelines often recommend sustaining or enhancing the abundance of conifers and longer-lived, often later successional, hardwood species [9]. The greater longevity of conifers and later successional hardwoods compared to early successional species provides for greater continuity of riparian function and larger potential tree sizes, resulting in higher inputs of coarse woody debris into aquatic habitats in the long run.

While management guidelines generally do not discourage silvicultural activities in riparian areas, managers may nevertheless forego harvests in RMZs because of uncertainties about the ability to regenerate desirable tree species (*i.e.*, conifers, later successional species) and the ability to maintain riparian functions that are dependent on trees [11]. There have been only a few experimental studies that have examined regeneration responses to partial harvesting treatments of RMZs within the context of riparian management guidelines that aim to sustain tree-derived functions and increase the component of more desirable tree species [e.g. [12] [13]].

Here we experimentally investigated the regeneration response to partial harvesting treatments in riparian areas that prescribed different levels of residual basal area within fixed-width RMZs. Specifically, we investigated how species of differing successional status (early, mid-, late) and growth forms (conifers, hardwoods, shrubs) regenerated under residual basal areas of 16 $m^2 \cdot ha^{-1}$ and 8 $m^2 \cdot ha^{-1}$. This experiment was conducted in mature mixed-species riparian forests dominated by early successional species, including trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) and a smaller component of conifers and later successional hardwoods. Our applied goal was to provide managers with information about approaches for managing similar riparian areas in ways that might reduce the density of early successional species and increase the abundance of later successional and conifer species.

2. Materials and Methods

2.1. Study Area

This study was conducted in eight forested riparian areas in the Laurentian Mixed Forest Province of Minnesota. The province is as a broad ecotone between the eastern deciduous forest and boreal forest biomes. It has a temperate climate with mean annual temperatures between 1.1˚C and 3.9˚C, and average annual precipitation between 56 and 81 cm [14]. Soils originated from Pleistocene till [15] and include well drained loamy sands that are shallow to bedrock in the uplands and sandy loams in lower landscape positions.

The eight study sites were selected in 2003 to meet the following criteria: 1) riparian forests were located adjacent to perennial streams that were less than 6 m in width; 2) a minimum contiguous forested area of 6.5 ha with a minimum of 183 m of stream frontage; 3) forests were mature and well-stocked in both the riparian zones and adjacent uplands.

Prior to treatment, dominant tree species included paper birch, trembling aspen, balsam fir (*Abies balsamea*), black ash (*Fraxinus nigra*), sugar maple (Acer saccharum), red maple (*Acer rubrum*), and basswood (*Tilia americana*), with lesser amounts of northern red oak (*Quercus rubra*), bur oak (*Quercus macrocarpa*), green ash (*Fraxinus pennsylvanica*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), big-tooth aspen (*Populus grandidentata*), balsam poplar (*Populus balsamifera*), yellow birch (*Betula allegheniensis*), silver maple (*Acer saccharinum*), ironwood (*Ostrya virginiana*), and northern white cedar (*Thuja occidentalis*). Collectively, early successional species (paper birch, trembling aspen, big-tooth aspen, and balsam poplar) comprised around 52% of the total basal area.

2.2. Experimental Design and Treatments

At each study site (sites treated as blocks for statistical analysis), two 3.2 ha treatment stands were delineated on one side of the stream, with the two stands separated by at least 61 m of unharvested forest (**Figure 1**). Within each treatment stand, a 0.8 ha riparian management zone (RMZ) was delineated along the length of the stream (183 m) that extended 46 m towards the upland, a width that corresponds to recommended RMZ widths for even-age management in the state of Minnesota [16]. The remainder of the treatment unit (2.4 ha) was outside of the RMZ and considered to be upland forest.

In each block, the following treatments were assigned to the two experimental units: 1) upland clearcut-RMZ uncut (RMZC) and 2) upland clearcut-RMZ partially harvested (RMZH) to a residual basal area of 16 $m^2 \cdot ha^{-1}$ (33% reduction) or 3) upland clearcut-RMZ partially harvested (RMZL) to a residual basal area of 8 $m^2 \cdot ha^{-1}$ (66% reduction). Only one of the two RMZ harvest treatments was assigned to each block due to space constraints; the result was an incomplete block design (see Statistical Analysis). To lessen confounding impacts of harvesting on streams, the RMZC treatment was always established upstream of the RMZH or RMZL treatments. The tree retention levels tested in this study fell within the range of residual basal area values recommended for RMZs in Minnesota [16]. Marking of residual trees followed riparian guidelines for Minnesota by reserving, where possible, longer-lived species, conifers, and hard mast-producing species.

Timber harvesting operations were conducted by experienced operators on frozen ground when sufficient snow had accumulated during the winter of 2003-2004 using conventional harvesting equipment (*i.e.*, feller-buncher and grapple skidder).

2.3. Vegetation Sampling

In each stand, five transects were established running perpendicular to the average stream meander, originating at the stream bankfull edge and terminating in the upland (**Figure 1**). Five vegetation measurement plots were established on each transect; four plots (each 4.6 m wide by 7.6 m long = 34.8 m^2) located in the RMZ and one plot located in the upland area outside of the RMZ (**Figure 1**). The first RMZ plot was established at the stream bankfull edge. The distance between the remaining RMZ plots varied because plots were constrained to be centered within major geomorphic features (*i.e.*, floodplain, terrace, hillslope), but generally the second RMZ plot was 9.1 m. from the stream, while the third plot was 22.9 m. from the stream. The fourth RMZ plot was always located 3 m. inside of the RMZ-upland boundary. The upland plot was always established 22.9 m. outside of the RMZ-upland boundary. Each treatment unit contained a total of 25 plots (5 transects × 5 plots).

Woody vegetation was sampled using a nested plot design. Species and diameter at 1.4 m (breast height = dbh) of trees (dbh ≥ 12.7 cm) and saplings (2.5 ≤ dbh < 12.7 cm) were sampled in the 4.6 m × 7.6 m plots. Woody stems (shrub species and advance tree regeneration) with dbh < 2.5 cm but ≥0.8 m tall were sampled in two 0.6 m × 4.6 m (2.8 m^2) plots nested within ends of the larger overstory plot. Small woody stems (<0.8 m tall) were tallied in six 0.6 m × 0.6 m (0.36 m^2) regeneration plots nested within each of the 2.8 m^2 plots. Vegetation was measured in the summer before harvesting and again five years after the harvest, after the majority of the growing season had elapsed, but prior to leaf senescence.

2.4. Statistical Analysis

Due to the variation in composition among the eight study blocks and to facilitate statistical analyses, we com-

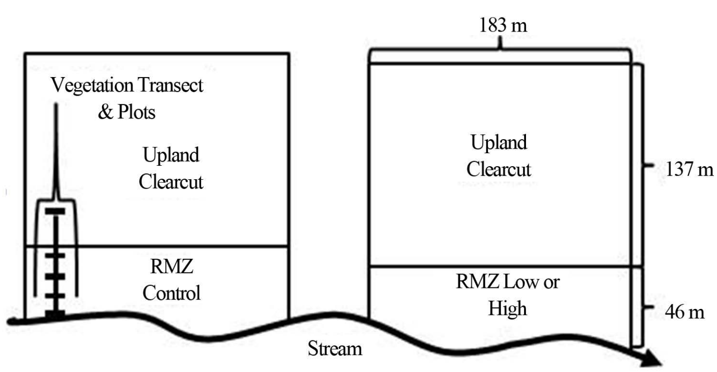

Figure 1. Study site layout illustrating treatment unit dimensions and vegetation sampling plot layout.

bined species into broader groups that reflected successional status and growth form. Groups included early successional hardwoods (paper birch, trembling aspen, big-tooth aspen, balsam poplar), mid-successional hardwoods (black ash, northern red oak, bur oak, green ash, silver maple, yellow birch, and American elm), late successional hardwoods (sugar maple, red maple, basswood, ironwood), and conifers (balsam fir, white spruce, black spruce, northern white cedar). Woody shrubs included mountain maple (*Acer spicatum*), alder (*Alnus* spp.), serviceberry (*Amelanchier* spp.), dogwood (*Cornus alternifolia*, *Cornus sericea*), hazel (*Corylus americana*, *Corylus cornuta*), honeysuckle (*Lonicera* spp.), cherry (*Prunus pensylvanica*, *Prunus virginiana*), and willow (*Salix* spp.). We summarized changes (between pre-harvest and 5th year post-harvest) in the proportional contribution to total density (in the sapling and regeneration layers) of each of these broad species groups (early, mid-, late successional, conifers, shrubs). For example, early successional hardwoods might have contributed 20% to total sapling density before harvest, but 60% after harvest, for a change of +40%.

Differences among treatments in basal area and stem density were assessed using an incomplete block mixed-model ANOVA with eight replicates for the control treatment (RMZC) and four replicates each for the riparian harvest treatments (RMZH, RMZL). Block was the random effect and basal area was the fixed effect. Pre- and post-harvest responses were analyzed separately. Some variables, including pre-harvest late successsional regeneration, 5th year early successional saplings, mid-successional trees, mid-successional saplings, late successional saplings, and regeneration were square-root transformed to meet the assumption of normality and homogeneity of variances. An alpha level of ≤0.05 was considered statistically significant. Statistically significant models were further investigated using a set of orthogonal contrasts that compared 1) the RMZCs to the pooled partial harvesting treatments and 2) the RMZHs to the RMZLs. All statistical analyses were conducted using SAS 8.02 [17]. For comparative purposes, we included data from the adjacent upland clearcuts in the results, but we did not include these data in the statistical analyses because the upland clearcut treatment was confounded with location in our design.

3. Results

3.1. Tree Layer

Mean pre-harvest basal area was 23.7 $m^2 \cdot ha^{-1}$ and did not differ statistically among the (future) RMZ treatments ($p > 0.05$; **Table 1**). Densities of early, mid- and late successional hardwood species, as well as conifers and total density, were not significantly different among treatments before harvest. Five years after harvest, residual basal areas reflected the harvest intensity gradient from the RMZC to the RMZL treatments (**Table 1**). Additionally, there was a statistically significant difference among treatments in total tree density ($p = 0.025$), with higher densities in the RMZCs than in the pooled harvest treatments ($p = 0.01$), but no significant differences between the two RMZ treatments ($p > 0.05$). There were trends in densities among treatments for all species groups that largely paralleled the gradient in basal area reduction (**Table 1**); however, due to high variation, these densities were not statistically different among the treatments. As expected, tree densities for all groups of trees and total density were substantially lower in the adjacent clearcuts than in the RMZ treatments.

3.2. Sapling Layer

Before harvest, total sapling density, as well as densities of hardwoods, conifers, and woody shrubs (that were large enough to be classified as saplings) did not differ statistically among (future) treatments (**Figure 2(a)**). Five years after harvest, total density of saplings did not differ among treatments, but there were differences among treatments in early successional hardwoods ($p = 0.03$; **Figure 2(b)**), with higher density in the RMZL compared to the RMZH treatment ($p = 0.012$). Moreover, early successional hardwood densities were higher in the clearcut uplands than either of the RMZ harvest treatments. The change in proportional contribution to total sapling density of early successional hardwoods after five years was small (< ±5%) in the RMZC and RMZH treatments, but was high and positive in the RMZL treatment (+13%) and the clearcut uplands (+56%), reflecting the substantial increases in sapling density of this group in these treatments (**Table 2**).

Densities of mid- and late successional hardwoods declined from the control to the RMZL treatment (**Figure 2(b)**), but the differences among treatments were not statistically significant. Proportional contribution to total sapling density of these groups did not change appreciably (≤ ±5%) by five years after harvest (**Table 2**).

Conifer densities were not statistically different among RMZ treatments (**Figure 2(b)**) and changes in proportional contribution to total sapling density were low (< ±5%). In contrast, the proportional contribution of

Table 1. Tree layer[a] characteristics in riparian management zone treatments.

	Pre-Harvest			Post-Harvest (5 years)			Upland Clearcut	
	RMZC[b]	RMZH[c]	RMZL[d]	RMZC	RMZH	RMZL	Pre	Post
Basal Area ($m^2 \cdot ha^{-1}$)	23.9 (1.8)[e]	25.7 (3.9)	21.6 (4.6)	23.7 (2.1)	15.6 (2.5)	8.0 (1.6)	23.9 (2.5)	1.1 (0.5)
Total Density ($stems \cdot ha^{-1}$)	1486 (114)	1463 (161)	1366 (116)	1431 (163)	877 (156)	576 (183)	1463 (109)	185 (69)
Early Successional[f] Density ($stems \cdot ha^{-1}$)	613 (119)	675 (217)	682 (185)	536 (126)	284 (124)	213 (116)	771 (143)	62 (35)
Mid-Successional[g] Density ($stems \cdot ha^{-1}$)	284 (163)	274 (252)	106 (72)	274 (158)	222 (198)	62 (22)	96 (49)	35 (27)
Late Successional[h] Density ($stems \cdot ha^{-2}$)	195 (91)	195 (104)	222 (222)	213 (101)	161 (82)	62 (42)	292 (148)	0 (0)
Conifers[i] ($stems \cdot ha^{-1}$)	395 (126)	319 (156)	356 (193)	408 (158)	213 (104)	240 (124)	301 (96)	89 (47)

[a]Diameter at 1.4 m ≥ 12.7 cm; [b]RMZC = uncut (control) RMZ; [c]RMZH = RMZ cut to 16 $m^2 \cdot ha^{-1}$; [d]RMZL = RMZ cut to 8 $m^2 \cdot ha^{-1}$; [e]Means ± 1 standard error; [f]Early successional includes paper birch, trembling aspen, big-tooth aspen, and balsam poplar; [g]Mid-successional includes black ash, green ash, northern red oak, bur oak, silver maple, yellow birch, and American elm; [h]Late successional includes sugar maple, red maple, basswood, and ironwood; [i]Conifers includes balsam fir, white spruce, black spruce, and northern white cedar.

conifers to total sapling density declined by nearly 19% in the clearcut (**Table 2**). Woody shrub densities were reduced by harvest (**Figure 2(b)**), although they did not differ statistically among RMZ treatments. Densities were lower in the upland clearcuts compared to the RMZ treatments. Proportional contribution of shrubs to total sapling density declined in all treatments. The decline was small (−3.9%) in the RMZC treatment (**Table 2**), but larger in the other RMZ treatments (−11.3% in RMZH; −15.9% in RMZL) and the upland clearcut (−29.7%).

3.3. Regeneration Layer

Densities of hardwood groups were low before harvest and did not differ statistically among (future) treatments (**Figure 3(a)**). Densities of conifers and woody shrubs were higher than those of hardwoods, but were variable and their densities, as well as total regeneration density, did not differ statistically among (future) treatments. Five years after harvest, total density in the regeneration layer differed statistically among treatments ($p = 0.04$), with higher densities in the pooled harvest treatments compared to the RMZC treatment ($p = 0.03$), but no statistical difference between the two partially harvested RMZ treatments. Densities of early successional hardwoods after harvest differed statistically among treatments ($p < 0.001$; **Figure 3(b)**), with higher densities in the pooled harvest treatments compared to the RMZC treatment ($p = 0.002$) and higher densities in the RMZL compared to the RMZH treatment ($p = 0.03$). Densities in the clearcut uplands were substantial higher than in the partially harvested RMZ treatments. Change in proportional contribution of early successional hardwoods to total regeneration density was positive for all treatments (**Table 2**), but not particularly high (< +5.4%), indicating that the relative densities of this group were not substantially changed by year five, mostly because sucker stems had grown into the sapling layer by this time.

Densities of mid- and late-successional hardwoods did not differ statistically among treatment five years after harvest and were similar to pre-harvest levels, with small changes in proportional contribution to total density (< ±5.3%), with the exception of late successional hardwoods in the RMZH treatment, which were substantially reduced (−11.9%). Conifer densities were reduced from pre-harvest levels in all treatments, including a 24% - 46% reduction in proportional contribution to total density (**Table 2**), but densities did not differ significantly among treatments.

Woody shrub densities differed among treatments five years after harvest (**Figure 3(b)**), with densities in the pooled harvest treatments statistically higher than in the RMZC treatment ($p = 0.03$) and densities in the RMZL treatment higher than in the RMZH treatment ($p = 0.04$). A commensurate large increase (21.1% to 40.6%) in the proportional contribution of shrubs to total regeneration density was observed in all treatments (**Table 2**).

4. Discussion

An important question for forest managers is how to balance extracting timber from riparian areas with sustaining riparian functions that depend on the regeneration of desirable tree species and species groups (e.g., con-

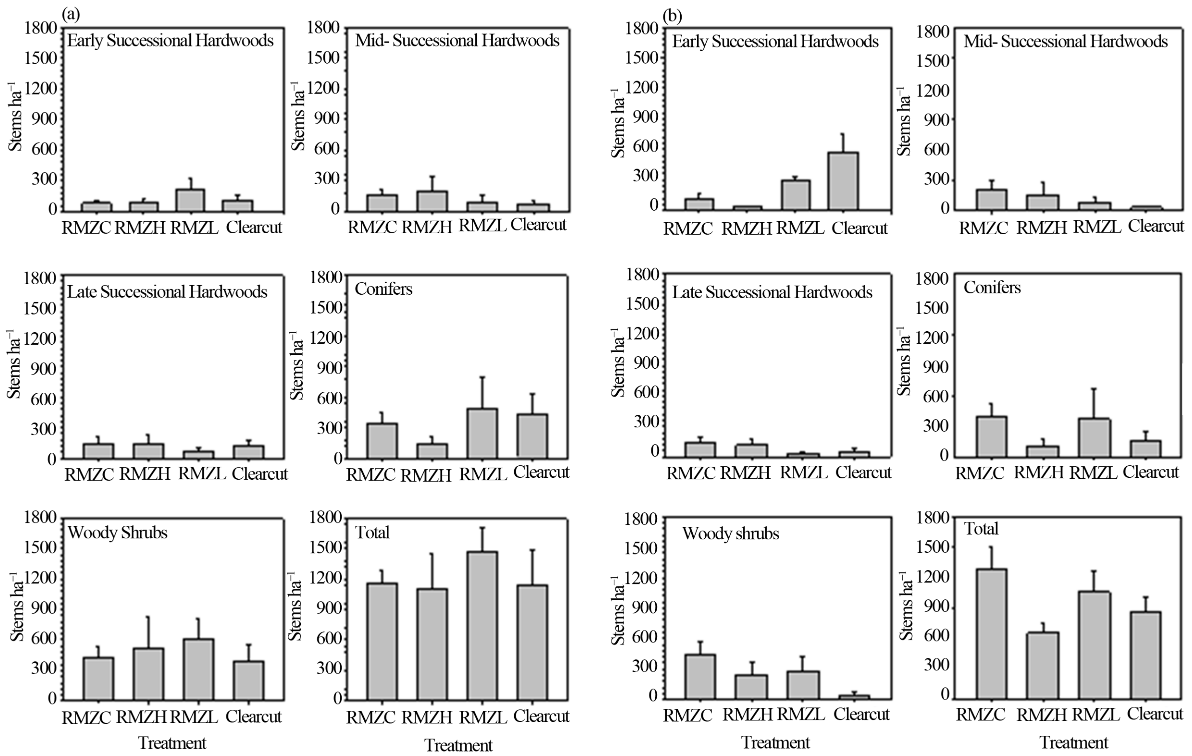

Figure 2. Sapling (2.5 < dbh < 12.5 cm) densities of species groups before harvest (a) and five years after harvest (b) See text for explanation of treatments and species groups.

Table 2. Change (from pre-harvest to five years after harvest) in proportional contribution to total density of different successional classes and growth forms in the different treatments.

Treatment[a]	Sapling Layer					Regeneration Layer				
	Early[b]	Mid-[c]	Late[d]	Conifers[e]	Shrubs[f]	Early	Mid-	Late	Conifers	Shrubs
RMZC	1.9	2.4	−2.0	1.6	−3.9	1.4	5.3	3.9	−31.9	21.1
RMZH	−3.0	4.8	4.6	4.8	−11.3	3.7	1.9	−11.9	−23.9	30.1
RMZL	13.2	1.3	−1.1	2.5	−15.9	3.7	1.7	0.5	−45.9	40.0
Upland										
Clearcut	56.1	−2.6	−5.2	−18.6	−29.7	5.4	−0.9	−5.1	−40.1	40.6

[a]RMZC = uncut (control) RMZ; RMZH = RMZ cut to 16 $m^2 \cdot ha^{-1}$; RMZL = RMZ cut to 8 $m^2 \cdot ha^{-1}$. [b]Early successional includes paper birch, trembling aspen, big-tooth aspen, and balsam poplar. [c]Mid-successional includes black ash, northern red oak, bur oak, green ash, silver maple, yellow birch, and American elm. [d]Late successional includes sugar maple, red maple, basswood, and ironwood. [e]Conifers includes balsam fir, white spruce, black spruce, and northern white cedar. [f]Shrubs include the woody species mountain maple, speckled alder, serviceberry, dogwood, honeysuckle, cherry, willow, and hazel species.

ifers, later successional species). This is particularly important in the water-rich Great Lakes regional landscape where a high percentage of the forest is riparian. For example, one estimate indicates that 37% of commercial forests in Minnesota are within 57 m of surface water [18], a distance that places the bulk of this forest within Minnesota's recommended RMZ width guideline of 46 m [16]. Consequently, a management objective for a mixed riparian forest like the one we examined will likely include managing for timber but in ways that: 1) reduce the density of early successional species, which in the Lake States often includes aspen and birch; and 2) regenerating and enhancing the proportion of longer lived, late-successional hardwoods and conifers.

The partial harvest treatments in the RMZs we examined were successful at meeting the first part of this ob-

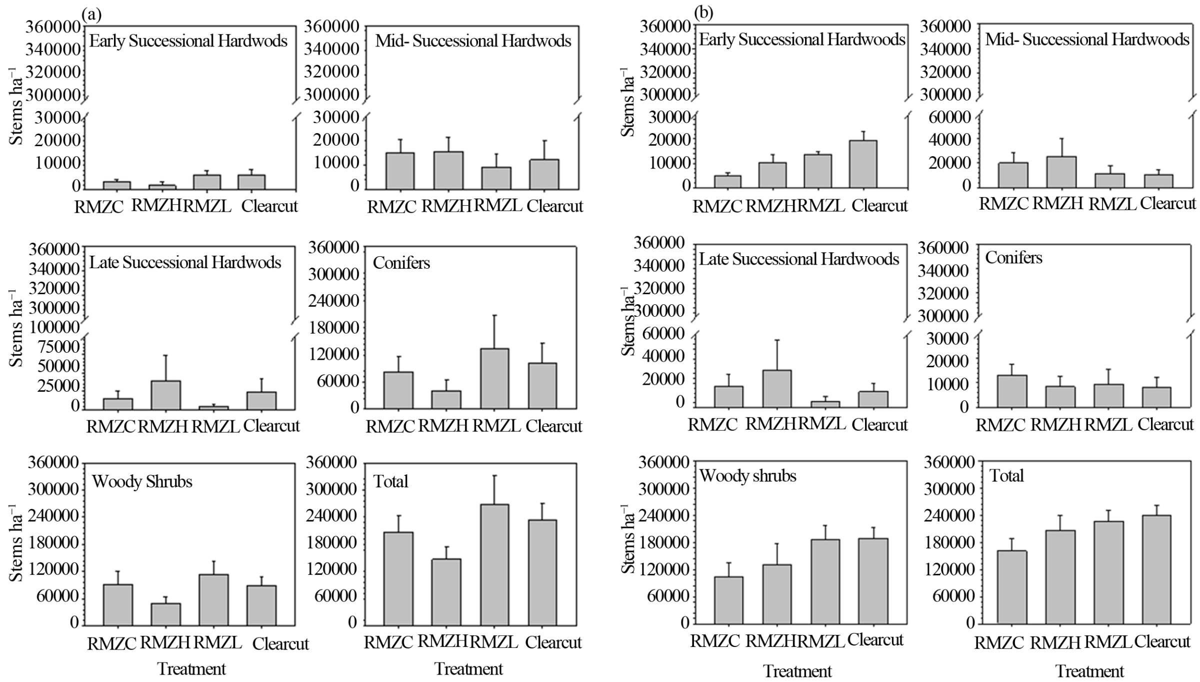

Figure 3. Regeneration (dbh < 2.5 cm) densities of species groups before harvest (a) and five years after harvest (b) See text for explanation of treatments and species groups.

jective. While early results (1 and 3 years after harvest) indicated that aspen sucker densities in the RMZs were within the range of acceptable stocking [13], after five years, this stocking had declined to levels that were less than one-third the stocking densities for aspen in similar aged clearcut stands [19] [20] and much less than the densities in the adjacent clearcuts we examined, especially in the RMZH treatment. While the density of early successional taxa did increase in parallel with the decreasing basal area of residual trees (from RMZC to RMZL), and the proportional composition of total sapling density for aspen and birch increased by 13.2% in the RMZL treatment, these relatively low basal areas still apparently checked sucker and seedling establishment or survival, relative to clearcuts, similar to findings from other studies [21]-[23].

The second part of the management objective, that of enhancing the abundance of later successional hardwoods and conifers, was largely not accomplished. Despite reserving mid- and later successional hardwood species and conifers as future seed sources in the overstory, these species were not able to capitalize (at least in the first 5 years) on the reduced density of early successional hardwoods. In fact, the proportional contribution to total regeneration density of conifers declined substantially in all RMZ treatments, including the controls, with a particularly strong decline in the RMZL treatment. We hypothesize that increases in solar radiation and temperature, which may have affected conifers even in the controls through edge effects [24] [25], may have caused moisture stress and mortality in spruce and fir seedlings [26] [27].

The increase in proportional contribution of woody shrubs, mainly beaked hazel and mountain maple, to total density in the regeneration layer of all RMZ treatments, and particularly in the RMZL treatment, may have further contributed to the limited regeneration success of trees. Resource preemption by a woody understory layer [28]-[30], and beaked hazel in particular [31], is recognized as a deterrent to the regeneration of trees. Thus the response of shrubs to harvesting in this study may have restricted the establishment of new trees and/or the growth of seedlings into the sapling size class. This inhibition appears to have been somewhat less in the RMZH compared to RMZL treatment.

While our treatments did not result in significant increases in densities of trees species deemed especially desirable in riparian settings (mid- and later successional hardwoods, conifers), our results do point to some practical guidance to managers working in such settings. First, leaving a residual basal area of 16 $m^2 \cdot ha^{-1}$, as we did in our RMZH treatment, was effective at limiting the regeneration density of early successional species (mostly aspen) to a greater degree than 8 $m^2 \cdot ha^{-1}$ in the RMZL treatment. Ultimately this reduction should be important for creating greater opportunities for establishment and growth of the other species groups. Secondly, although the density of sapling-sized woody shrubs declined following treatment, woody shrub density increased substantially in the regeneration layer. The increased abundance of these keen competitors may be an obstacle to the establishment, survival, and growth of more desirable tree species in riparian areas. This combination of responses—suppression of early successional species and expansion of woody shrubs, suggests the need for additional activities to promote regeneration of mid- and later successional hardwoods and conifers. In particular, competition control to reduce shrub densities [12] [13], along with seeding or planting of desired species, may be needed to ensure regeneration success.

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