Influence of Site Preparation on Natural Regeneration and Understory Plant Communities within Red Pine Shelterwood Systems

Anthony W. D'Amato, John Segari, and Daniel Gilmore

ABSTRACT

The effects of four site preparation treatments on natural red pine (*Pinus resinosa*) regeneration and understory plant community composition were examined within a red pine shelterwood in northern Minnesota. Site preparation treatments were applied after shelterwood establishment cuttings and included underburning (B), herbicide (H), mechanical mulching (M), and M + H treatments. Natural red pine regeneration densities were greatest in M only and M + H treatments, whereas there was no statistical difference in red pine regeneration between H, M, and untreated control areas 5 years after treatment application. Ordination and indicator species analysis of the understory communities revealed distinct understory assemblages corresponding to each treatment. *Diervilla lonicera* and *Pteridium aquilinum* were significant indicators of burned communities, whereas *Maianthemum canadense* and *Rubus strigosus* and red pine were significant indicators of the H only and M + H treatments, respectively. Overall, densities of shrub species did not change after B, whereas reductions in shrub densities were observed for all other treatments. Findings from this work indicate that viable site preparation treatments exist for securing natural red pine regeneration within shelterwood systems, thus providing an alternative or supplement to artificial regeneration efforts in regions with low risk of shoot blight infection.

Keywords: red pine, site preparation, shelterwood methods, prescribed burning, understory vegetation

Clearcutting-based regeneration methods represent the most common approach to securing regeneration within many forest types across the United States (Barrett 1995, Schutz 1997, D'Amato et al. 2009). Nonetheless, aesthetic and ecological concerns associated with traditional clearcutting methods have led to an increased interest in the application of even-aged regeneration methods based on extended regeneration periods (e.g., shelterwood systems) and two-aged systems with high levels of structural retention (e.g., clearcutting with reserves; Franklin et al. 1997, D'Amato et al. 2009). Although clearcutting-based systems largely use planted seedlings for regeneration, shelterwoods and other high forest methods primarily rely on natural regeneration (Matthews 1989). As such, the increasing emphasis on these methods requires a renewed understanding of the factors affecting successful regeneration within these systems, particularly for intolerant species historically regenerated using primarily clearcutting-based methods (e.g., Zenner et al. 1998).

An increasingly common challenge associated with securing regeneration within forest systems, independent of regeneration method used, is the presence of recalcitrant understory layers composed of highly competitive herbaceous and woody plant species (Royo and Carson 2006). In many cases, these understory conditions have developed through alterations to historic disturbance regimes that have favored the expansion of native species (e.g., Tappeiner et al. 1991), the introduction and proliferation of exotic invasive species (e.g., Merriam and Feil 2002), and/or selective herbivory of tree seedlings by deer (e.g., Horsley and Marquis 1983, de la Cretaz and Kelty 2002). Because of the strong influence these understory layers have on the composition and development of tree regeneration (George and Bazzaz 1999, Dovčiak et al. 2003), evaluations of the efficacy of traditional and novel site preparation techniques at minimizing the impacts of these competitive conditions are proving increasingly useful for ensuring the creation of suitable regeneration conditions within many forest types (de la Cretaz and Kelty 2006).

Red pine (*Pinus resinosa*) represents one of the more ecologically and commercially important species within the northern Lake States region (Johnson 1995). This species is commonly regenerated through clearcutting followed by planting; however, there is increasing interest in the use regeneration methods, such as shelterwood and seed tree methods, that better approximate the historic range of disturbance severities for the region (Gilmore and Palik 2006). For example, recent work has highlighted the historic role of moderate-severity natural disturbances, such as surface fires and blowdown, in generating two-aged and uneven-aged red pine systems in Minnesota (Fraver and Palik in press). Although several silvicultural trials

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Anthony D'Amato (damato@umn.edu) and John Segari (segar009@umn.edu), Department of Forest Resources, University of Minnesota, 1530 Cleveland Avenue N, 115 Green Hall, St. Paul, MN 55108. Daniel Gilmore (dgilmore@umn.edu), Oneida County Health Department, Utica, NY 13502. *The authors thank Ron Severs at the Cloquet Forestry Center for assistance with study layout and treatment implementation. In addition, John Blanchard, Charles Kramer, and Nicholas Reep assisted with data collection and processing. Funding for A. D'Amato was provided by the Minnesota Agriculture Experiment Station.*

This article uses metric units; the applicable conversion factors are meters (m), 1 m = 3.3 ft; square meters (m^2), 1 m^2 = 10.8 ft^2; hectares (ha), 1 ha = 2.47 ac; kilograms (kg), 1 kg = 2.2 lb.

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Table 1. Description of site preparation treatments and average overwood densities (standard errors in parentheses) within a red pine shelterwood in northern Minnesota.

Treatment	Description	Sampling years	Overwood density (m^2 ha^{-1})
B	All understory shrubs and trees felled by brushsaw in June 2001 Prescribed burn in August 2001	2000, 2002, and 2006	25.6 (2.8)
H	Application of granular hexazinone at 3.3 kg ha^{-1} in June 2001	2000, 2002, and 2006	24.4 (0.5)
M	M treatment using hydraulic mulcher applied in October 2000	2000, 2002, and 2006	24.8 (1.1)
M + H	M treatment using hydraulic mulcher applied in October 2000 Application of glyphosate at 2.48 kg ha^{-1} in September 2003	2000 and 2006	23.9 (1.7)
C	No treatment	2002 and 2006	26.0 (3.1)

Establishment cuttings occurred in 2000 and all sampling was done at the end of the growing season within a given year.

have examined the efficacy of shelterwood methods for regenerating red pine, this work has relied on artificial regeneration or has been limited to poorer sites with low levels of understory competition (Benzie and Alm 1977, Chapeskie et al. 1989, Ontario Ministry of Natural Resources [OMNR] 1998). As such, there is little information on the effectiveness of this regeneration method at securing natural regeneration or the types of site preparation techniques that reduce understory competition on more productive red pine sites. In particular, many red pine–dominated forests are now characterized by highly competitive understory layers dominated by hazel (*Corylus cornuta*), which create a significant barrier to the recruitment of red pine and other species (Tappeiner 1971). This species is characteristic of other native shrub species that form recalcitrant understory layers in that it is capable of rapid, clonal spread after disturbance and is often thicket forming (Young and Peffer 2010). Although recent work has suggested that the presence of hazel may facilitate the growth and survival of planted white pine seedlings (*Pinus strobus*) within red pine–dominated forests, the nature of interactions between this species and planted red pine seedlings is largely negative (Montgomery et al. 2010). Nonetheless, little is known about how these understory conditions affect natural seedling recruitment within red pine shelterwoods. To address these information gaps, we evaluated the efficacy of four different site preparation treatments at promoting red pine natural regeneration within shelterwood systems. Specific objectives included (1) assessing the influence of mechanical, chemical, and underburning site preparation treatments on natural regeneration of red pine and (2) quantifying the influence of these treatments on the structure and composition of understory plant communities.

Methods

Study Area

This study was conducted within a 90-year-old, natural red pine stand located on the Cloquet Forestry Center within northern Minnesota (N 46.704, W 92.525). The site is classified as a Northern Dry-Mesic Mixed Woodland (FDn33) based on the Minnesota Department of Natural Resources (MNDNR) habitat classification system (MNDNR 2003). Soils within this area are loamy sands derived from glacial outwash and are somewhat excessively drained with low fertility and low organic matter (Lewis 1978). Terrain is level to gently sloping (0–2%) and the site index for red pine on the site was 16.8 m at 50 years.

The stand used in this study had been thinned several times before the onset of the study starting in 1950, with subsequent thinnings occurring in 1960, 1970, and 1985. In August 2000, a shelterwood establishment cutting that reduced the residual basal area to an average of 25 m^2 ha^{-1} was implemented within a uniform shelterwood system. This residual basal area represents the upper range of recommended overwood cover for red pine within this shelterwood variant (Puttock and Bevilacqua 1995) and was chosen to maximize seed rain coverage throughout the stand. Red pine was the only overstory tree species at the time of establishment cutting because of the preferential removal of other minor species during previous thinnings (e.g., *Pinus banksiana*). Seed fall within the shelterwood areas was measured during the fall of 2000 and ranged from 720,000 to 1,270,000 seed ha^{-1}, which represents a heavy seed crop for this species (Cayford 1964). Germination tests conducted on a subsample of seeds indicated a viability rate of 84% (R. Severs, Cloquet Forestry Center, University of Minnesota, pers. comm., June 6, 2001).

Study and Sampling Design

A series of site preparation treatments were replicated five times within the shelterwood in a randomized, complete block design with blocking based on spatial location within the shelterwood. Each block was 0.5 ha and contained the following treatments applied within 0.1-ha treatment plots: mechanical mulching (M), M followed by herbicide release (M + H), herbicide only (H), underburning (B), and an untreated control (C; Table 1). Treatments were applied in a contiguous 3.2-ha portion of the shelterwood to ensure all plots had comparable overwood and soil conditions (Table 1).

Mechanical mulching treatments (M and M + H) were applied in October of 2000 using a midsize crawler pushing a hydraulic mulcher. This mechanical treatment incorporated most coarse woody debris and forest litter into the upper soils horizons and resulted in substantial scarification of the mineral soil (R. Severs, Cloquet Forestry Center, University of Minnesota, pers. observ., Oct. 1, 2000). For the M + H treatment, an herbicide release using glyphosate (Accord concentrate) was broadcast applied at a rate of 2.48 kg of active ingredient per hectare in September of the 3rd year of the study (2003) to determine the importance of follow-up release treatments in securing red pine regeneration on the mechanically treated plots (Table 1). The H treatment included the application of a broad-spectrum herbicide, granular hexazinone (Pronone 10G formulation, Pro-Serve, Inc., Memphis, TN) at 3.3 kg of active ingredient per hectare in June 2001. The B treatment was applied in August 2001. For this treatment, all understory shrubs and trees were felled with brush saws in June 2001, distributed across the site, and allowed to cure until August so as to carry the fire more effectively and uniformly. The underburn had moderate flame frontal intensity with flame lengths below 1 m and inspections of the burn area shortly after treatment implementation indicated that the burn consumed most of the aboveground vegetation present

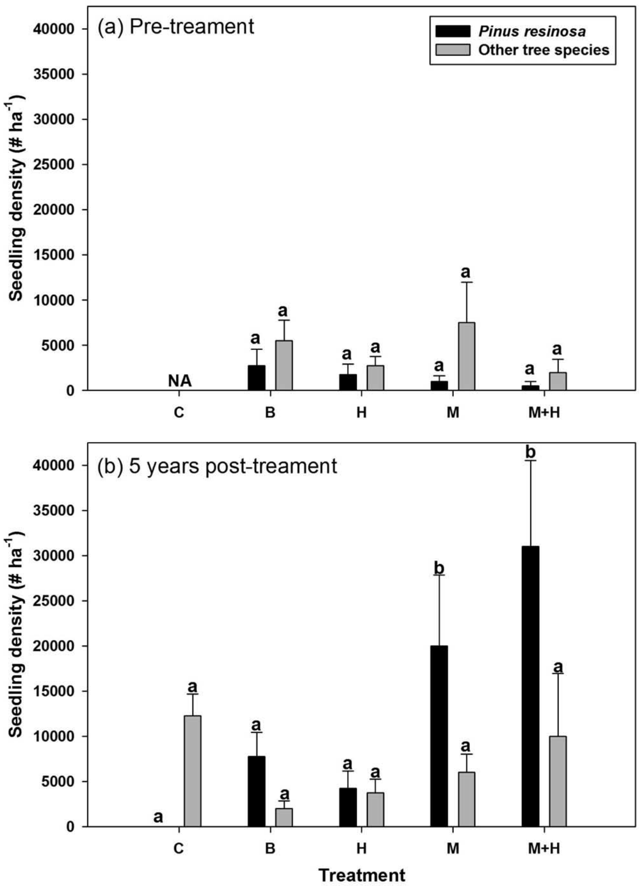

Figure 1. Densities of red pine and other tree seedlings within a red pine shelterwood (a) 1 year before and (b) 5 years after the application of B, H, M, and M + H site preparation treatments. Values represent means and associated standard errors and treatments with different letters within a species are significantly different at $P < 0.05$. Pretreatment data were not collected in untreated C areas. Other species included *A. rubrum, A. balsamea, P. glauca,* and *B. papyrifera.*

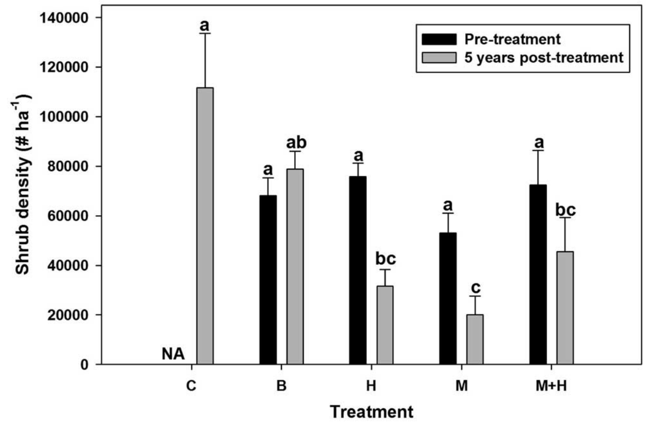

Figure 2. Shrub densities pretreatment and 5 years posttreatment within B, H, M, and M + H site preparation treatments. Values represent means and associated standard errors and treatments with different letters are significantly different at $P < 0.05$. Note pretreatment values were not collected for C treatments.

with slight penetration into the organic and upper mineral soil horizons (R. Severs, Cloquet Forestry Center, University of Minnesota, pers. observ., Aug. 9, 2001). There were no differences in pretreatment seedling or shrub densities among treatment plots (Figures 1 and 2).

Within each treatment block, eight 1-m^2 sample plots were permanently established in a systematic grid before treatment implementation. Measurements within each plot included tree seedling and shrub stem densities by species and percent cover of herbaceous plants by species. No effort was made to differentiate between seedlings established before treatment and those that established posttreatment due to the removal of pretreatment vegetation by many of the treatments and the low number of pretreatment seedlings within these areas. Measurements were collected on treatment plots before treatment and at 1 and 5 years after treatment implementation, with the exception of the M + H treatment for which only pretreatment and 5-year posttreatment data were collected (Table 1). The C plots were not measured before treatment implementation and were installed and measured at 2 and 5 years posttreatment. As a result, we have restricted our comparisons with C plot conditions to the final measurement year.

Data Analysis

The effect of site preparation treatments on tree and shrub densities were examined using a mixed model analysis of variance (ANOVA) in which the block was treated as a random effect and treatment was treated as a fixed effect, after the SAS MIXED Procedure (2001; SAS Institute, Inc., Cary, NC). Given the differences in treatment and measurement years between some treatments, we restricted ANOVAs to pretreatment and 5-year posttreatment data. In cases in which the overall model was significant, Tukey's multiple comparison procedure was used to test for differences between site preparation treatments. For all ANOVAs, residuals were checked for normality (Kolmogorov-Smirnov test) and homogeneity of variances (Levene test) and data were transformed as necessary. Multivariate tests for differences in the composition of understory vegetation (herbs, shrubs, and seedlings) between treatments were conducted using multiresponse permutation procedures (MRPP) in PC-ORD Version 5.13 (McCune and Mefford 2006). MRPP is a nonparametric, randomization-based multivariate test of differences between groups that compares the plots within a priori groups to a random allocation of plots (McCune and Grace 2002). Sørensen distances were used to calculate average within-group distances for MRPP. Indicator species analysis (Dufrêne and Legendre 1997) was used to describe how well certain understory species differentiated between stands treated with different site preparation treatments

Nonmetric multidimensional scaling (NMS; McCune and Grace 2002) was used to graphically display and interpret compositional differences within the understory plant communities among treatments after 5 years. This and other ordination techniques are useful for summarizing plant community data and highlighting patterns in composition related to particular treatments or environmental conditions. As was the case for MRPP, NMS used Sørensen distances to calculate a distance matrix for the 20 treatment blocks. To reduce noise in the data set, species with fewer than three occurrences were removed from the data matrices (McCune and Grace 2002). The "slow-and-thorough" autopilot mode of NMS in PC-ORD was used to generate solutions. This procedure determines the optimal ordination solution by stepping down in dimensionality from a six-axis to one-axis solution using 40 runs performed on real data followed by 50 Monte Carlo runs using random data (McCune and Mefford 2006). Optimal dimensionality was based on the number of dimensions with the lowest stress (i.e., smallest departure from monotonicity in the relationship between distance in the original space and distance in the reduced ordination space, McCune and Grace 2002). Relationships between species abundance and NMS axis scores were explored using Kendall's τ statistic (SAS Version 9.1, 2004; SAS Institute, Inc.). For all analyses, a value of $P \leq 0.05$ was defined as statistically significant.

Results

Natural Regeneration

Site preparation significantly affected the density of red pine regeneration 5 years after treatment ($F = 12.03$; $P = 0.0006$). Red pine regeneration densities were greatest in M and M + H (Figure 1), whereas there was no statistical difference among H, B, and untreated C areas 5 years after treatment application (Figure 1). The density of other species did not vary among site preparation treatments 5 years after treatment ($F = 1.74$; $P = 0.2118$; Figure 1). Other tree species regenerating within each treatment included red maple (*Acer rubrum*; all treatments), balsam fir (*Abies balsamea*; all treatments), white spruce (*Picea glauca*; M and H treatments), and paper birch (*Betula payrifera*; C, M, and M + H treatments).

Understory Structure and Composition

Site preparation significantly affected shrub densities ($F = 8.49$; $P = 0.0004$) with most treatments generally reducing shrub densities relative to pretreatment levels and those found in control areas 5 years posttreatment (Figure 2). Posttreatment shrub densities were significantly lower in the H, M, and M + H treatments relative to C plots, whereas there was no difference between B and C plots (Figure 2). The slight increase in shrub densities observed in the B plots was caused by an increase in bush honeysuckle (*Diervilla lonicera*) stems coupled with little decrease in hazel (*C. cornuta*) stems (Figure 2). Hazel densities declined in all treatments; however, it remained the dominant shrub species on all treatments.

Distinct understory species assemblages corresponded to each treatment 5 years after treatment application (MRPP, $A = 0.13$; $P < 0.001$). In particular, pairwise comparisons of species composition between treatments indicated that C plots differed from all site preparation treatments. Similarly, composition of B plots was significantly different from the other site preparation treatments, whereas there was no difference between the H, M, and M + H treatments. There were no differences in species composition between the areas receiving site preparation treatments before treatment application ($A = 0.04$; $P = 0.802$).

The differences in understory species composition between treatments was also illustrated by the general separation of points for several treatments in the ordination of understory vegetation (Figure 3), which explained 65% of the variation in the raw data (NMS ordination, final stress = 12.55 and final instability = 0.000001). Most of the variation in understory vegetation among treatments was explained by axis 1 (33.8%), which ranged from plots experiencing site preparation treatments in the negative portion of axis 1 to untreated C plots in the positive portion (Figure 3). Correlations of species with this axis indicated there was greater abundance of graminoid species ($\tau = -0.69$), blackberry (*Rubus alleghaniensis*; $\tau = -0.36$), Virginia strawberry (*Fragaria virginiana*; $\tau = -0.30$), bracken fern (*Pteridium aquilinum*; $\tau = -0.29$), and red raspberry (*Rubus strigosus*; $\tau = -0.28$) within plots located in the negative portion of axis 1 and a greater abundance of large-leaved aster (*Aster macrophyllum*; $\tau = 0.29$) within plots in the positive portion (Figure 3).

The distribution of treatment plots along axis 2, which explained 31.2% of the variation, generally ranged from B and C treatments to plots experiencing M and M + H treatments. Plots within B and C treatments tended to have greater amounts of beaked hazelnut (*C. cornuta*) and Canada mayflower (*Mainthemum canadense*) because there was a significant negative correlation between the abundance of these species and axis 2 ($\tau = -0.37$ and -0.33; Figure 3). Species with a greater abundance within plots in the positive portion of axis 2 were moss species ($\tau = 0.60$), violet species (*Viola* spp.; $\tau = 0.46$), red pine seedlings ($\tau = 0.33$), and graminoid species ($\tau = 0.32$; Figure 3). Several species were identified as significant indicators of a given treatment (per Indicator Species Analyses; $P < 0.05$), driving the distinction between treatments. Bush honeysuckle and bracken fern characterized the B treatment, whereas Canada mayflower was an indicator for the H treatment, violet species was an indicator for the M treatment, and red raspberry and red pine seedlings were indicators for the M + H treatment.

Discussion

Increasing public and ecological concerns over the use of clearcutting is causing managers to revisit the use of regeneration methods, such as shelterwood methods, and variable retention harvest systems that maintain mature trees within forest stands during and after regeneration harvests (Franklin et al. 1997, Bliss 2000). For example, the percentage of land being regenerated using shelterwood methods in Minnesota doubled from 1996 to 2008 (D'Amato et al. 2009). Despite this increase, considerable knowledge gaps exist regarding the most effective approach to applying these methods, particularly in cases in which there is the potential for high levels of resource competition between understory shrubs and tree seedlings (Royo and Carson 2006). This study sought to address these gaps in knowledge by examining the effectiveness of four site preparation alternatives on the natural regeneration of red pine and associated vegetation in the understory. Our results suggest that the application of M treatments with and without a follow-up H application are most effective at creating favorable seedbed conditions for securing red pine regeneration during shelterwood establishment cuttings. The distinct understory plant communities characterizing these and the other site preparation treatments examined (H and B treatments) highlight that these treatments may also have lasting effects on native biodiversity and plant community structure.

Natural Regeneration

There is a tremendous range of site preparation treatments for creating favorable seedbed conditions for natural regeneration in shelterwood systems (Wagner and Colombo 2001). Within this study, the application of M and M + H applications were the most effective site preparation treatments for securing natural red pine regeneration. These results likely reflect the higher degree of soil disturbance and competitor root damage associated with these treatments relative to the other site preparation treatments examined (Lanini and Radosevich 1986). In particular, these treatments exposed considerable areas of mineral soil while also reducing shrub densities thus providing favorable establishment sites for red pine seedlings with low levels of initial competition.

Although the largest decrease in shrub densities was observed in the H only treatment, this treatment also contained the lowest number of tree seedlings, particularly red pine (Figure 1). These findings further underscore the importance of mineral soil exposure for securing red pine regeneration, because this treatment only served to

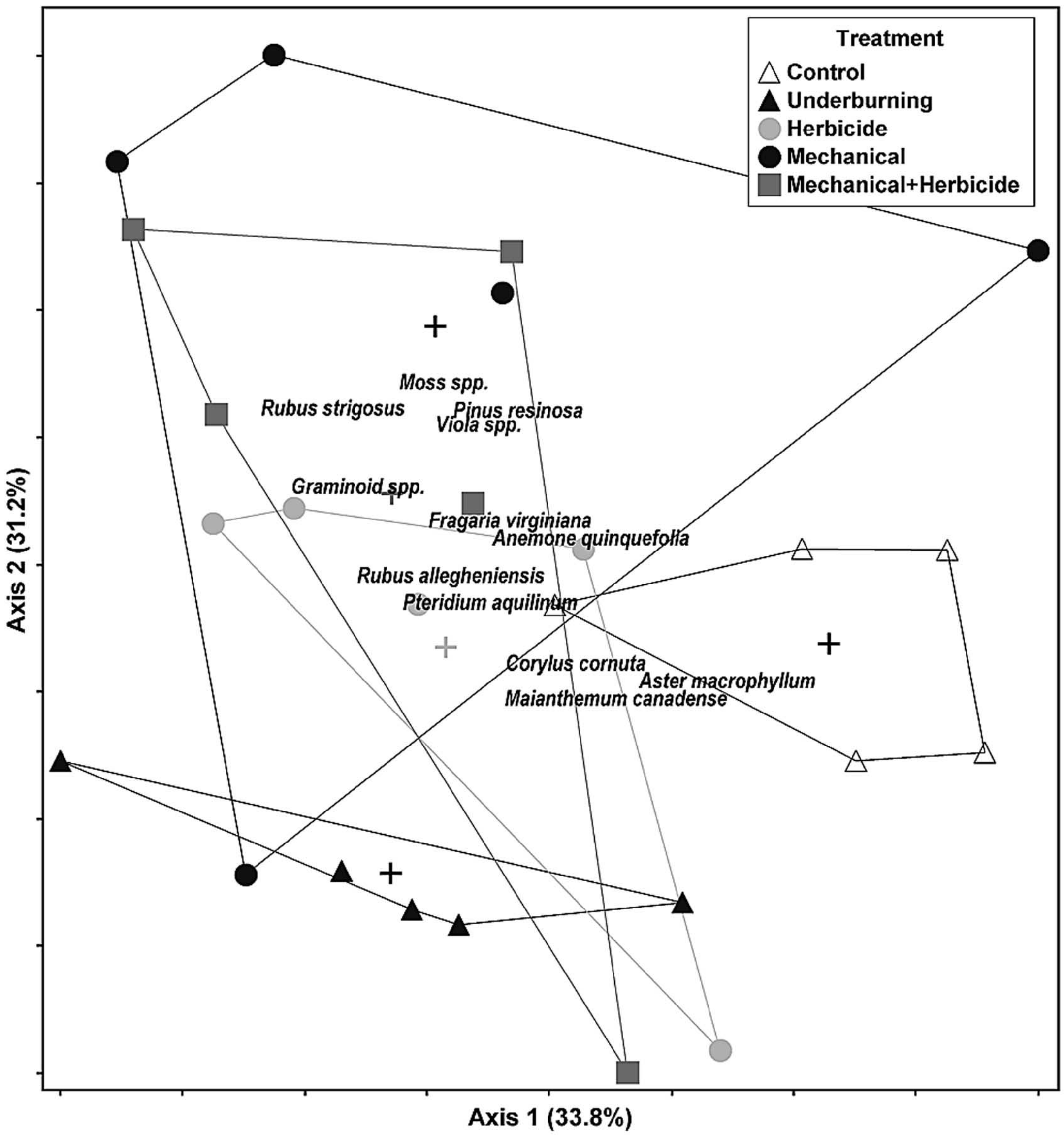

Figure 3. NMS ordination of understory vegetation composition 5 years after the application of each site preparation treatment. C, untreated control; B, underburning; H, herbicide; M, mechanical mulching; and M + H, mechanical mulching followed by herbicide treatment. Species listed are significantly correlated (Kendall's τ, $P < 0.05$) with either axes 1 or 2 and their location within ordination space is based on weighted averaging scores.

decrease levels of competition with no impact on the thickness of the organic soil horizon. The lack of difference in red pine regeneration densities between the M and M + H treatments indicates that H treatments applied after mechanical site preparation do not increase red pine seedling establishment and survival during the first 5 years relative to those observed after solely M treatments. As such, the increased cost of an H treatment may only be justified for stands in which competition is not controlled by M treatments.

Fire has historically played an important ecological role in red pine ecosystems (Rouse 1988) leading to numerous investigations into the effectiveness of prescribed burning treatments at reducing understory competition levels and creating favorable germination sites for the regeneration of this species (Buckman 1964, Henning and Dickmann 1996). Although underburning has been suggested as a technique for reducing competition and preparing seedbeds for red pine (McRae et al. 1994), our findings indicate that a single prescribed burn is not effective at creating favorable conditions for natural regeneration. In particular, the B treatment in this study did not change the density of shrub species and resulted in low levels of red pine regeneration. This effect can be ascribed to the vigorous root systems of bush honeysuckle and hazel (Tappeiner 1971). Both of these species are adapted to vigorous vegetative reproduction after fire and several studies have shown that multiple fires are required to suppress the resprouting of hazel (Buckman 1964, Neumann and Dickmann 2001). The response of bush honeysuckle to multiple fires is less certain with some studies showing continued increases in the density of this species after multiple fires (Ahlgren 1970), whereas others have shown initial increases in abundance followed by decreases with subsequent burns (Ahlgren 1966, Swan 1970).

Understory Composition

The understory species assemblages we observed in response to site preparation were largely reflective of the disturbance severity of a given treatment type and species life-history traits (Roberts 2004, 2007). In particular, treatments only impacting aboveground competition with little soil disturbance led to increases in the abundance of herbaceous and woody species adapted to resprouting and spreading via rhizomes and stolons after disturbance. This was highlighted by the indicator species for the B (bush honeysuckle and bracken fern) and H (*M. canadense*) treatments (Rowe 1983). In contrast, a species capable of regenerating from buried seed (*R. strigosus*) was an indicator of the M + H treatment reflecting the high levels of soil disturbance within this treatment (Mladenoff 1990). The high degree of variability in understory communities observed within M treatments likely reflects the varying degrees of soil disturbance and removal of preexisting vegetation by this treatment (Roberts 2007).

The documented treatment responses of the understory plant community can be useful for informing management prescriptions that aim to maintain native biodiversity, while also creating conditions suitable for natural red pine regeneration. All the site preparation treatments resulted in regeneration densities that met or exceeded minimum stocking levels for naturally regenerated red pine within the region (1000–4900 tph; OMNR 1998, Gilmore and Palik 2006), suggesting that treatment selection could be based on desired understory conditions versus adequate seedling densities. Of the treatments examined, B resulted in plant community composition that most closely resembled those found in C plots and natural red pine systems in the region (MNDNR 2003), suggesting this treatment may be useful for maintaining and restoring diversity within the understory layer (Neumann and Dickmann 2001). Nonetheless, long-term monitoring of these areas will be needed to evaluate the impacts of the high levels of shrub cover in these areas on red pine seedling survival and growth.

Conclusions

As management regimes continue to evolve to accommodate social and ecological considerations, managers are increasingly seeking alternative methods for securing regeneration relative to traditional clearcutting-based approaches. To this end, we sought to examine the effectiveness of different site preparation techniques at creating favorable regeneration conditions within a red pine shelterwood. Our findings highlight the importance of mineral soil exposure in securing high red pine regeneration densities within a shelterwood setting, with M treatments leading to the highest levels of recruitment. These highly stocked areas may also require precommercial thinnings to ensure the long-term growth and development of crop trees and these costs should be considered when evaluating the feasibility of a given site preparation treatment. Overall, this work shows that regeneration methods based on partial harvesting treatments can successfully regenerate red pine when appropriate site preparation treatments are applied. Nonetheless, these approaches should be limited to regions where there is a low risk of shoot blight infection from *Diplodia pinea* and *Sirococcus conigenus* (Albers 2008).

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