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# Alternative shelterwood approaches for natural regeneration of oak-dominated hardwood stands on mesic sites in southern New England

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## ABSTRACT

*Few studies have evaluated regeneration methods for oak-hardwood forests in Southern New England. Red oaks in second growth stands subjected to selective fellings (high-grading) on mesic sites are reportedly replaced by black birch, red maple and/or sugar maple. Such sites have proven difficult to secure oak regeneration. We studied establishment and growth of regeneration on a mesic-till soil supporting a one-hundred-year-old, even-aged, oak-hardwood stand. Treatments comprised three different shelterwoods – uniform, irregular, and group – versus a control. We monitored composition, density, and growth of regeneration over an eight-year period. Results showed that the uniform shelterwood, and to a lesser degree the irregular shelterwood, was characterized by vigorous regrowth of oak's key competitors, black birch and red maple. Results suggest that regeneration cuttings should be more opportunistically timed to oak masting and seedling establishment events, or that follow-up release treatments may be required to reduce competition around individual oak seedlings. The group shelterwood limited competitors, while maintaining a cohort of oaks that may be more competitive upon later release. Group shelterwoods may be another viable approach to developing red oak, particularly given unpredictable seed production and where intensive follow-up treatments are not feasible.*

**KEYWORDS.** Silvicultural methods, seedling establishment, regeneration cuttings, mixed-species, forest management

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# INTRODUCTION

Regeneration of oak has been widely recognized as a problem throughout its range (Lorimer 1993). Many studies have documented oak regeneration challenges under different silvicultural systems for upland oak-hardwood forests of the Southern Appalachian regions of the Carolina's and Tennessee (e.g. Parker and Swank, 1982; Beck and Hooper, 1986; Loftis, 1983; Loftis, 1990; Brose et al., 1999) and middle Appalachian forests of Pennsylvania, Virginia and West Virginia (e.g. Tryon and Carvel, 1958; Carvel and Tryon, 1961; Smith and Miller, 1987; Kays et al., 1988; Schuler and Miller, 1995; Fei et al., 2006; Steiner et al., 2008). With the absence of disturbance (in particular ground story fires), the oaks (particularly red oak, *Quercus rubra* L.) in eastern hardwood forests are often replaced by more mesic and or shade-tolerant competitors such as American beech (*Fagus grandifolia* L.), tulip poplar (*Liriodendron tulipifera* L.), black birch (*Betula lenta*), yellow birch (*B. alleghaniensis* Britton), red maple (*Acer rubrum* L.), or sugar maple, (*A. saccharum* Marsh.) (see Kelty and Nyland, 1981; Loftis, 1985; Abrams 1992; Brose et al., 1999). Most of these studies have demonstrated that shelterwoods timed to groundstory burning and/or the use of stem injection herbicides to take out competing shade tolerant understory are the most successful regeneration methods to retain oak in a new stand (Loftis, 1983; Smith and Miller, 1987; Loftis, 1990b; Schuler and Miller, 1995; Brose et al., 1999; Steiner et al., 2008).

In southern New England only one study has examined potential regeneration methods for oak and associated hardwoods. Ward and colleagues compared the growth and performance of regeneration in four treatments – a uniform shelterwood, diameter-limit cutting (high-grade), coppice with standards, an incomplete overstory removal (commercial clearcut), and a complete overstory removal (one-cut shelterwood) (Ward and Stephens, 1999, Ward et al., 2005). These treatments were all compared to an uncut control. Results showed regeneration density increased in all treatments as compared to the control except the diameter limit; that volume growth was lowest in the diameter-limit cutting; and that the shelterwood produced the highest commercial volumes in the long term by retaining a strong component of oak, while diameter-limit cutting had the lowest commercial volumes with a scarce amount of oak (Ward and Stephens, 1999; Ward et al., 2005). Furthermore, like other forests of the Appalachians, their studies showed that oak had significant competition from black birch, yellow birch and red maple (Ward and Stephens, 1993; 1994; 1996). Long-term plot records now show a strong decline in the dominance of oak with a shift to beech, maple and birch in Connecticut and Massachusetts (Ward and Barsky, 2000).

Other related studies to this regeneration issue in southern New England have largely focused on growth performance and pattern of regeneration within and across forest gaps (Hibbs, 1982; 1983) and experimental linear openings (Smith and Ashton, 1993; Liptzin and Ashton, 1999). In these studies, results show that for oak to be present in a stand it is essential to have it represented as advance regeneration prior to creating a canopy disturbance and that a nearby source of seed is needed for supplemental establishment thereafter (Smith and Ashton, 1993; Liptzin and Ashton, 1999). In addition, studies documenting the cohort dynamics of advance regeneration beneath closed canopied mature forest in southern New England have demonstrated the infrequent and episodic nature of recruitment, with oak showing the greatest variability in masting intervals (>10 y) and amounts, with significantly lower survival in the forest understory of mesic till soils (50% mortality after 4 y) than dry till soils (50% mortality after 8 y) (Ashton and Larson, 1996; Frey et al., 2007).

Problems with oak regeneration are likely a result of a combination of factors – an absence of ground story fire and subsistence agriculture (Abrams 1992; Brose et al., 1999; Abrams and Nowacki, 1992), high deer populations (Kittredege and Ashton, 1990; 1995); the high shade conditions of forest understories (Ashton and Berlyn, 1994; Ashton and Larson, 1996; Frey et al. 2007), infrequent establishment of oak cohorts (Frey et al., 2007), and a selective harvesting of trees by landowners that disproportionately removes the oak and hence the future seed source (Ward and Barsky, 2000). Literature that has reported on historical composition of forests in southern New England has shown that both prior to colonization (Native American) and the period after of land colonization and subsequent abandonment (1650-1900), disturbance regimes were created that favored a high component of oak (Day, 1953; Patterson and Sassaman, 1988; Abrams, 1992; Whitney, 1994; Foster et al., 2002; Parshall and Foster, 2002).

Given its ecological importance as a key component of the southern New England forest type (Abrams, 1992) and as the most important food source and habitat for wildlife (McShea et al., 2007), regeneration methods need to be developed that promote and retain oak. Based on past work by Ward et al. (2005) suggesting that shelterwood treatments were the most viable long-term regeneration method for southern New England forests, this study evaluated several shelterwood treatments to investigate performance of oak on a mesic-till site competitive for black birch, red maple and sugar maple. Treatments included a control (no treatment) that was compared to a uniform shelterwood; an irregular shelterwood where a proportion of the residual subcanopy was retained; and a group shelterwood in which openings were created that were half the height of the canopy. It was hypothesized that the uniform system would have higher regeneration densities and height growth, and a greater proportion of oak given the higher light conditions compared to the other treatments. It was also hypothesized that treatments maintaining a greater overstory basal area (group, irregular shelterwood) would promote proportionately higher densities and height growth of red maple and sugar maple, which are considered more shade tolerant (Burns and Honkala, 1990)

## METHODS

### Site description

This study was conducted at the Yale Myers Forest (41° 57′ N, 72° 07′W) located in northeastern Connecticut. This region is characterized by undulating ridge-valley topography ranging from 200-350 meters above sea level, an ancient geological landform comprised of schist-gneiss of metamorphic origin. The climate is cool temperate, with an annual rainfall of 1125mm, a mean summer temperature of 20°C, and a mean winter temperature of -4°C (Meyer and Plusnin, 1945). The forest is situated in a transition zone between the central hardwood of south coastal New England and the mixed hardwood-pine-hemlock forest of central New England (Westveld, 1956). The dominant canopy trees are red oak, red maple, sugar maple, black birch, hemlock (*Tsuga canadensis* L. Carriere) and white pine (*Pinus strobus* L.). Because of the variable till soils, undulating topography, and history of heavy land use and disturbance, the average stand size with uniform site, species composition and land use/disturbance history is about 2-4 ha (Yale Forest Records, 2000). This creates a very heterogeneous forest that characterizes much of southern New England (Meyer and Plusnin, 1945; Whitney, 1994).

Regeneration treatments for the study were undertaken in an even-aged 100 y old closed canopy forest (with occasional wolf trees) that succeeded from old-field pine that was cut out in the early 1900's and that originated on an old unimproved pasture in around 1850. The site is a mid-slope bench (slope 10-15%) with a northeast aspect. The soils are comprised of the Charlton-Chatfield series and can be considered the dominant upland mesic-till soil within the forest study site (Soil Conservation Service, 1975; 1981). These soils are very representative of both the eastern and western upland physiographic provinces of southern New England.

Experimental design

The original stand basal area comprised an oak canopy, with a subcanopy of red maple, black birch, sugar maple and some hemlock The stand also had occasional wolf trees of sugar maple and beech over 250 years old (Table 1). The development of the stand has been described by studies done in an adjacent area with a similar history and species composition (Oliver, 1978). Here several stem analysis and oak spacing studies have been done that showed that after the pine was cutover, sprout-origin red maple was the first to attain the regenerating forest canopy, interspersed by black birch (Oliver, 1978). Red oak did not attain the canopy until year 40, with the red maple and black birch receding to the subcanopy. Sugar maple has continuously grown slowly upward but still remains today in the subcanopy (Oliver, 1978; Kittredge, 1988).

In 1998, three experimental shelterwood treatments were established (Fig.1). Treatments included: 1.) a uniform shelterwood in which mature canopy dominant oak trees (mean dbh = 60cm) were left at 12-18 m spacing, with occasional single tree reserves that were either sub-canopy red maple (5-7 ha$^{-1}$), or wolf trees (sugar maple, beech, 2.5 ha$^{-1}$); 2.) an irregular shelterwood which maintained the same overstory oak spacing as the uniform shelterwood along with wolf trees and subcanopy reserves of red maple and black birch, but which retained a higher number of single tree subcanopy reserves primarily of sugar maple (mean dbh = 20cm; 40 ha$^{-1}$); 3.) a group shelterwood treatment where openings were created that had a diameter (based on canopy crown projection to the ground) equivalent to canopy height (22.5m), in which all trees >5 cm dbh were removed; and 4.) a control where the original stand was left untreated. Each treatment area comprised 2.4 ha (total area ~10 ha) in which every tree over 5cm dbh was stem mapped. Treatment areas were oriented perpendicular to the slope (SE-NW) and adjacent to each other as 150m x 150m blocks.

Harvest treatments were created in the winter of 1998-1999, when the ground was frozen, using a TIMCO feller-buncher for all trees less than 40cm dbh. The larger trees were hand felled using a chainsaw. All trees were directionally felled, limbed and bucked on site, and the slash crushed to the ground (<1m height) and dispersed. Merchantable logs were carried off site using a forwarder.

## Measurements

Within each treatment area, four 40m long transects were established, 20m apart and perpendicular to the slope. Each transect had four circular plots spaced at 10m intervals.

Plots were centered on PVC pipe and sampled a 1m$^2$ area. Within each plot, all seedlings were recorded by species and measured for height. Measurements were made pre-treatment (1998), and then in 1999, 2003, and 2006. Seedlings were also measured for root-collar diameter using a digital caliper. A complete inventory of red maple stump sprouts (the only species to stump-sprout post-treatment) was undertaken within each treatment unit in 2006 to determine sprout density and height growth.

Tree dbh was recorded for the overstory canopy tree species using fixed area plots (15m radius) positioned at the PVC plot centers. Measurements were taken both pre-treatment (1998) and post-treatment (1999 and 2006).

## Data analysis

All analyses were performed using transects as the sampling unit, with plots treated as subsamples. Statistical analyses of composition of regeneration using density, aggregate height (Fei et al., 2006), and root collar basal area was performed using a permutational multivariate analysis of variance approach (Anderson, 2001; McArdle and Anderson, 2001). This method uses a chosen distance measure and permutational procedures to produce p-values and test significance of main effects and interactions, and generate pair-wise multiple comparisons. The software package PERMANOVA (Anderson, 2001) was used for these tests, using Bray-Curtis distance measures, on 1000 permutation and pair-wise multiple comparisons. Analyses were conducted separately for seedling density, height, and root collar diameter. Data were square root transformed to improve normality. Means were compared using pair-wise tests generated by permutational procedures. All tests were evaluated at a level of significance of $\alpha$=0.05.

To assess density and growth (mean height and root collar diameter) for individual species we used a simple analysis of variance (PROC GLM, SAS (2006)). Tukey's HSD test was used for multiple comparisons of treatment effects where the overall model was significant. In addition, analysis of temporal recruitment patterns was performed for individual species using a repeated measures analysis of variance (PROC GLM, SAS (2006)) using both univariate and multivariate approaches. Recruitment data were square root transformed to improve normality. Results were evaluated based on both methods, and where sphericity assumptions were violated the Huynh-Feldt adjusted p-values were used.

## RESULTS

### Composition and density

Overall, eight years after the shelterwood treatments, seedling regeneration was dominated by red oak, followed by black birch, red maple, and sugar maple (Table 2). However, differences in species composition were evident between treatments (Table 3). Compositional differences were particularly apparent between the uniform and irregular treatments compared to the group shelterwood and the uncut control. The uniform and irregular treatments had higher black birch and red oak densities (10 and 2-3 times greater, respectively) but lower red maple seedling densities (less than half) compared to the group and control. Red maple sprout densities were highest in the uniform shelterwood, driven by higher density of stumps and sprouts/stump. Red maple sprout densities were intermediate in the irregular shelterwood, infrequent in the group shelterwood, and non-existent in the control.

Height and root collar diameter

There was strong canopy stratification among species in height growth eight years after the initial shelterwood treatments (Table 3, Fig. 2a, b). In general, red maple sprouts formed the tallest strata, two to three times taller than black birch, which average 2-5 times the height of associated seedlings of red maple, red oak, and sugar maple. Height stratification and overall height growth among all species increased from control, to group, to irregular, to uniform treatment as amount of basal area removed and canopy opening increased.

Basal area based on root collar diameters differed somewhat from height patterns (Fig. 2c). Black birch dominated the uniform and irregular treatments, where it occurred in high densities. Red maple sprout basal area was approximately 25% of black birch, its much lower densities compensated by vigorous growth by individual sprouts. Red oak basal area was significantly lower than both the birch and red maple sprouts in the uniform and irregular treatments. Red oak was followed by sugar maple and red maple seedlings in the uniform and irregular treatments.

Basal area for all species was reduced substantially in the group shelterwood, and relative basal areas of black birch and red maple declined dramatically such that there were no differences evident. This was also true in the control, where the low stature of all species resulted in negligible measurements of basal area.

### Recruitment

Regeneration densities varied in time, generally increasing following the shelterwood treatments, although patterns differed between species (Fig. 3, Table 4). Sharp increases in black birch and red oak recruitment were evident, certainly reflecting increased opportunities for new seedling establishment with canopy opening. However, the increase in red oak densities across all treatments (including the control) was attributable to a mast year that occurred in these stands in 2002 (Frey et al., 2007), four years after shelterwood treatment. By 2004 (5 years after treatment), seedling densities for red oak and black birch had peaked and were declining as the regenerating stands began to thin. Sugar maple densities continued to increase over the study period, also attributable to a series of mast events in 2004, and 2006 (Frey et al., unpublished data).

## DISCUSSION

Divergent regeneration patterns were evident among the different shelterwood treatments. The uniform shelterwood, and to a lesser degree the irregular shelterwood, was characterized by vigorous regrowth of oak's key competitors, black birch and red maple. Early dominance by birch and maple following canopy removal is typical in southern New England hardwood forests (Oliver, 1978; Oliver and Stephens, 1977; Smith and Ashton, 1993; Liptzin and Ashton, 1998). Black birch is a vigorous, light-seeded pioneer following canopy removal (e.g. Catovsky and Bazzaz, 2000), and the development of dense black birch regeneration has previously been observed in shelterwood treated stands in southern Connecticut (Ward and Stephens, 1999). Red maple regeneration was primarily dominated by stump sprouting, which responded rapidly to canopy opening (Fei and Steiner, 2009) and formed an upper stratum above the black birch, but with a highly clumped spatial distribution reflective of its pre-disturbance distribution in the stand (Beck and Hooper, 1986). Red maple regeneration was most vigorous in the uniform treatment. Increasing light and resource levels associated with increased canopy removal favor competing vegetation (e.g. Frey et al., 2003), and likely enhanced the vigor of oak's competitors in the uniform, and to lesser extent the irregular, shelterwood treatment. A matrix of birch with clumped distribution of overtopping red maple represents the competitive environment in which red oak develop in southern New England hardwood stands (Oliver, 1978).

Density of red oak regeneration, like the birch and maple, increased with canopy removal. Oak recruitment and establishment events are characteristically irregular and unpredictable owing to masting behaviour, but a mast year in 2002 (Frey et al., 2007) and possibly enhanced acorn production by residual trees (Healy et al., 1999), supplemented the sparse advance regeneration and contributed to increased oak establishment in the shelterwood stands and the undisturbed control. Densities were highest in the uniform and irregular shelterwoods. While oaks are understood to lag behind red maple and black birch in height growth during early development (Oliver, 1978), the red oak component in this study lagged far behind in height. This may be attributable to the relatively low densities of advance regeneration of red oak prior to cutting, as vigorous established red oak are widely understood to be necessary for successful oak regeneration following disturbance (e.g. Loftis, 1990). In northern oak forests (northern Appalachians, central hardwoods) high densities of seedlings may compensate for smaller stature in determining successful oak regeneration following regeneration treatments (Ward and Stephens, 1999; Fei al., 2005). It seems likely that a sparse cohort of advance regeneration, most of which originated from a 1993 mast year (Frey et al. 2007), and a 3-year lag in subsequent oak recruitment following harvest, has put oak regeneration in an apparently weak competitive position. Other studies on drier till sites, where laurel (*Kalmia latifolia* L.) is an understory competitor for growing space with oak regeneration, have shown that shelterwoods timed to groundstory burns are very effective at releasing oak advance regeneration (Moser et al., 1996). However, it remains to be seen whether mesic sites can be managed in this way. Lastly, plantings of red oak with the use of shelters, once thought a potential satisfactory way of supplementing oak advance regeneration, have been shown to almost completely fail (Kittredge et al., 1992).

The group shelterwood was characterized by a marked reduction in the development of oak's competitors. Poor development of a black birch and red maple stratum may have reflected a poor light environment, or some other microclimatic factor (e.g. temperature). Not surprisingly the red oak component did not exhibit elevated growth, but did appear to be growing as favorably in the group shelterwood as in the more open uniform and irregular treatments. The net effect is that the relative competition has been greatly reduced for red oak in this treatment. This "femelschlag" (expanding gap) approach has been developed in German forests to favor the development of vigorous regeneration before subsequent removal of the adjacent stand (Puettmann et al., 2009). It appears that smaller gaps, though seemingly unfavorable to the growth of relatively shade intolerant red oaks, may be advantageous to oak species that show persistent survival in shaded conditions (Frey et al., 2007). Indeed, if this treatment favors more vigorous development of oak advance regeneration while limiting the development of competitors, it may greatly improve successful oak development when subsequent treatments remove the adjacent overstory.

## MANAGEMENT IMPLICATIONS

Shelterwood regeneration methods, which release advance regeneration of oak, are widely perceived to be the optimal approach for securing oak in hardwood stands. Where advance regeneration of oak is limited or lacking, shelterwood treatments such as the uniform and irregular treatments that remove a significant portion of the basal area will increase light and resource levels and thereby favor growth of competitors, such as black birch and red maple, which can rapidly colonize the site. Even with subsequent masting and establishment events increasing the oak seedling densities, it appears unlikely that oak will readily close the growth deficit. This suggests that regeneration cuttings either need to be more opportunistically timed to take advantage of seedling establishment events, or alternatively that follow up release treatments such as cleaning be employed to reduce red maple and black birch competition around individual oak seedlings.

Another alternative suggested by this study is to open the canopy more slowly to limit the development of competitors. Where advance regeneration is poorly established, shelterwood treatments that control competition and extend the window for oak establishment may be very advantageous. The group shelterwood limits the birch and red maple development, while maintaining a cohort of red oak that is likely to be more competitive upon release. The group shelterwood may thus be a viable approach to developing red oak, particularly given unpredictable seed production and where more intensive follow-up treatments are not logistically or economically viable.

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**List of Tables:**

Table 1. Stand characteristics for different shelterwood stands pre (1998) and post (1999) treatment. 1a. Stand basal area by species ($m^2$/ha). 1b. Stand density by species (stems/ha). Other = American beech, black cherry (*Prunus serotina* Ehrh.), basswood (*Tilia americana* L.); Subcanopy = musclewood (*Carpinus caroliniana* Walt.), hop hornbeam (*Ostrya virginiana* P. Mill.).

Table 2. Regeneration densities (stems/ha) for seedling and sprout regeneration. Mean and standard error (SE) provided for pre-harvest (1998) and 8-years post-harvest (2006).

Table 3. Permutational multivariate analysis of variance (PERMANOVA) for seedling composition between shelterwood treatments, based on density, aggregate height, and basal area (root collar). Data represent p-values; significant effects are in bold, multiple comparisons are not adjusted.

Table 4. Results of repeated measures analysis of variance for recruitment over study period. S=species, Tr=shelterwood treatment, T=time, df=degrees of freedom, SS=sum of squares, Pr=probability, H-F=Huynh-Feldt correction.

**List of Figures:**

533 Table 1.

534

1a. Basal area ($m^2$/ha)

| | Uniform | | Irregular | | Group | | Control |
|---|---|---|---|---|---|---|---|
| **Species** | **1998** | **1999** | **1998** | **1999** | **1998** | **1999** | **1998** |
| Black birch | 4.22 | 0.17 | 1.29 | 0.00 | 0.51 | 0.52 | 4.58 |
| Hemlock | 4.68 | 1.40 | 0.33 | 0.00 | 0.86 | 0.87 | 3.12 |
| Other | 0.14 | 0.00 | 0.21 | 0.19 | 0.00 | 0.00 | 0.54 |
| Paper birch | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.06 |
| Red maple | 3.88 | 0.60 | 2.86 | 0.08 | 3.61 | 2.17 | 4.78 |
| Red oak | 13.90 | 6.46 | 21.16 | 8.94 | 12.10 | 7.41 | 15.78 |
| Sugar maple | 2.72 | 2.89 | 3.27 | 1.91 | 4.42 | 4.30 | 1.28 |
| Subcanopy | 0.02 | 0.00 | 0.00 | 0.03 | 0.11 | 0.00 | 0.01 |
| White ash | 1.29 | 0.00 | 0.39 | 0.40 | 1.48 | 0.96 | 0.00 |
| White pine | 0.00 | 0.00 | 1.09 | 1.13 | 0.00 | 0.00 | 0.00 |
| TOTAL | 31.01 | 11.51 | 30.60 | 12.67 | 23.09 | 16.22 | 31.17 |

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Table 1.

1b. Density (stems/ha)

| | Uniform | | Irregular | | Group | | Control |
|---|---|---|---|---|---|---|---|
| **Species** | **1998** | **1999** | **1998** | **1999** | **1998** | **1999** | **1998** |
| Black birch | 88 | 4 | 31 | 4 | 19 | 19 | 138 |
| Hemlock | 77 | 19 | 4 | 0 | 8 | 8 | 50 |
| Other | 8 | 0 | 8 | 8 | 0 | 0 | 42 |
| Paper birch | 4 | 0 | 0 | 0 | 0 | 0 | 27 |
| Red maple | 207 | 19 | 177 | 19 | 200 | 119 | 219 |
| Red oak | 107 | 46 | 173 | 58 | 69 | 42 | 119 |
| Sugar maple | 299 | 42 | 392 | 276 | 434 | 250 | 265 |
| Subcanopy | 4 | 0 | 0 | 0 | 12 | 0 | 4 |
| White ash | 8 | 0 | 8 | 8 | 54 | 35 | 0 |
| White pine | 0 | 0 | 4 | 4 | 0 | 0 | 0 |
| TOTAL | 802 | 131 | 795 | 376 | 795 | 472 | 864 |

Table 2.

| | 1998 | | 2006 (8 years post-harvest) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Overall | | Uniform | | Irregular | | Group | | Control | |
| | Mean | SE | Mean | SE | Mean | SE | Mean | SE | Mean | SE |
| **Seedlings/ha** | | | | | | | | | | |
| Black birch | 6872 | 4373 | 45625 | 19321 | 39375 | 7730.8 | 625 | 625 | 0 | 0 |
| Red maple | 27488 | 7497 | 17500 | 4677 | 14375 | 4130 | 13750 | 6250 | 13750 | 5052 |
| Red oak | 2499 | 1249 | 71250 | 28732 | 46250 | 15828 | 28125 | 9540 | 9375 | 3590 |
| Sugar maple | 3124 | 625 | 5000 | 3385 | 0 | 0 | 1875 | 1875 | 0 | 0 |
| Other | 6247 | 1249 | 4375 | 2135 | 9375 | 2772 | 625 | 625 | 8125 | 7315 |
| **Red maple sprouts** | | | | | | | | | | |
| Stumps/ha | - | - | 187.7 | 103.7 | 156.8 | 11.1 | 80.3 | 34.6 | - | - |
| Sprouts/stump | - | - | 32.1 | 2.5 | 17.3 | 2.5 | 4.9 | 0.0 | - | - |
| Sprouts/ha | - | - | 2494.7 | 684.2 | 1378.3 | 196.4 | 155.6 | 0.0 | - | - |

Table 3.

| **Treatment** | | | **Density** | **Height** | **Basal area** |
|---|---|---|---|---|---|
| Uniform | vs. | Irregular | 0.0280 | 0.3027 | 0.0799 |
| Uniform | vs. | Group | 0.0390 | 0.0390 | 0.0390 |
| Uniform | vs. | Control | 0.0270 | 0.0270 | 0.0270 |
| Irregular | vs. | Group | 0.0230 | 0.0230 | 0.0230 |
| Irregular | vs. | Control | 0.0300 | 0.0300 | 0.0300 |
| Group | vs. | Control | 0.1389 | 0.3726 | 0.0250 |

546 Table 4.

| Source | df | Type III SS | Mean SS | F | Pr>F | H-F Adj Pr>F | Wilks-Lambda |
|---|---|---|---|---|---|---|---|
| S | 4 | 347.36 | 86.84 | 3.43 | 0.0144 | | |
| Tr | 3 | 32.5 | 10.83 | 0.43 | 0.7336 | | |
| S*T | 12 | 330.09 | 27.51 | 1.09 | 0.3898 | | |
| T | 5 | 428.01 | 107.00 | 4.59 | 0.0014 | 0.0253 | <0.0001 |
| T*S | 16 | 1523.26 | 95.20 | 4.08 | <0.0001 | 0.0021 | <0.0001 |
| T*Tr | 12 | 319.70 | 26.64 | 1.14 | 0.3438 | 0.3439 | 0.2181 |
| T*S*Tr | 48 | 703.15 | 14.65 | 0.63 | 0.9716 | 0.8493 | 0.2554 |

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Figure 1.

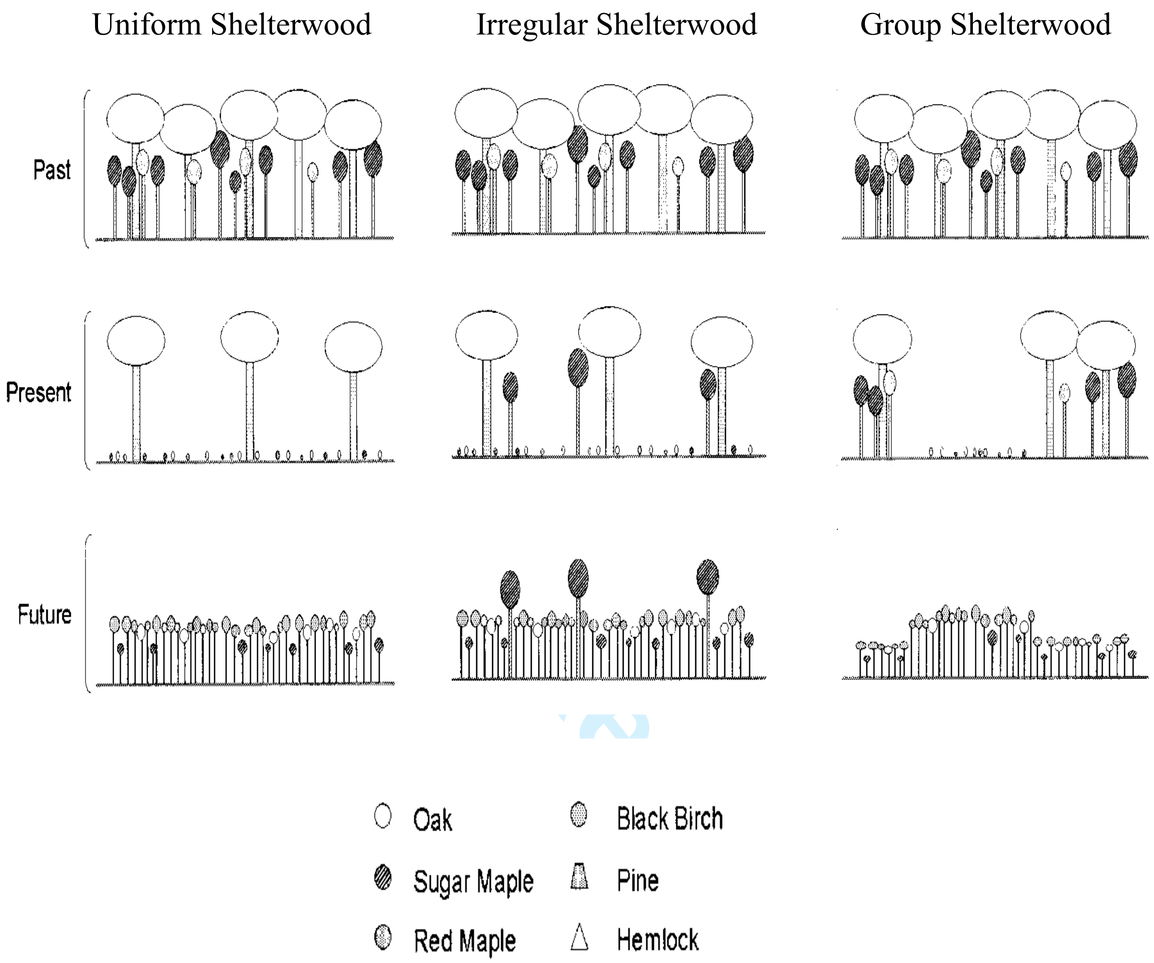

Uniform Shelterwood
Irregular Shelterwood
Group Shelterwood
Past
Present
Future
Oak
Black Birch
Sugar Maple
Pine
Red Maple
Hemlock

Figure 2.

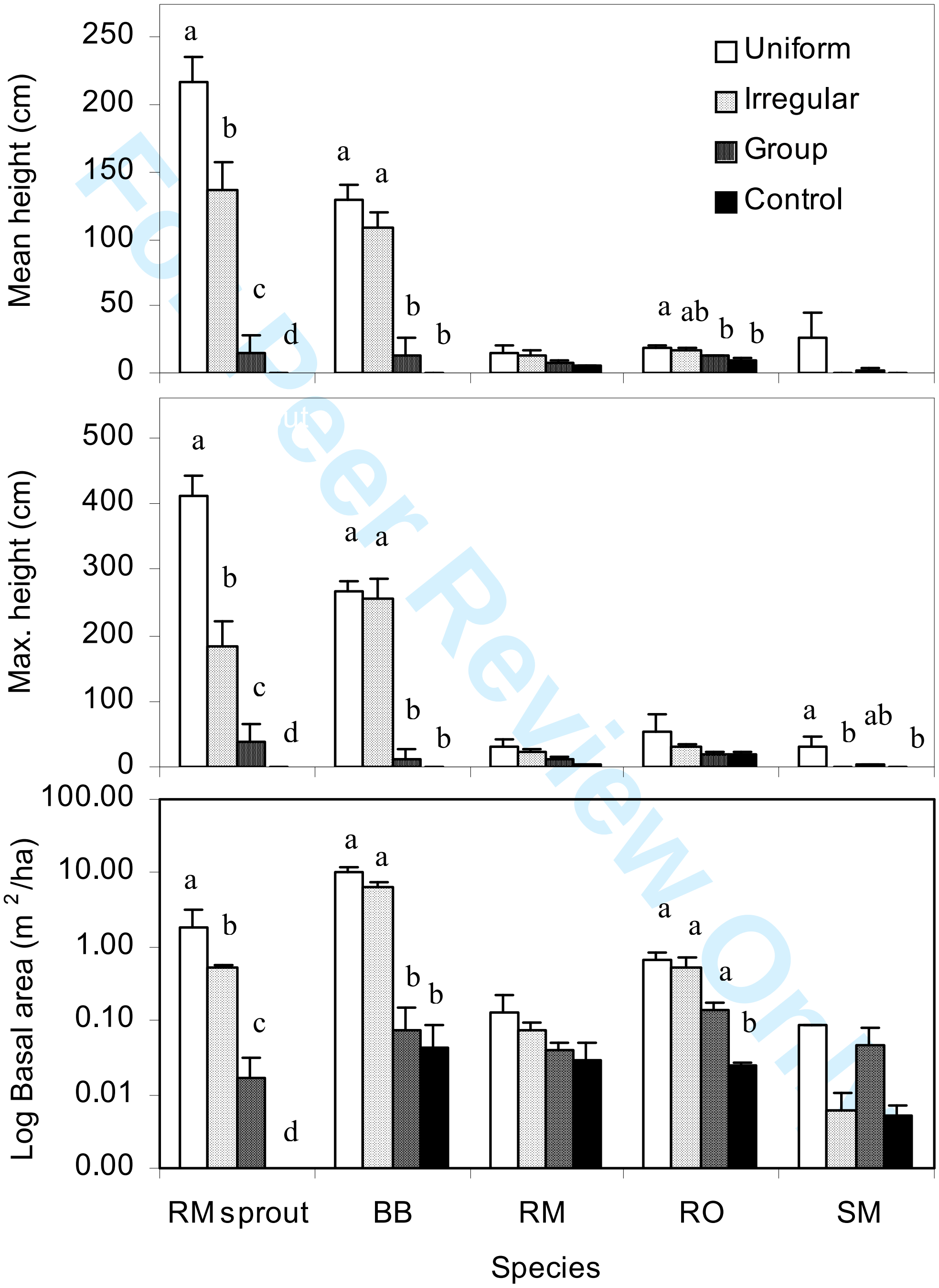
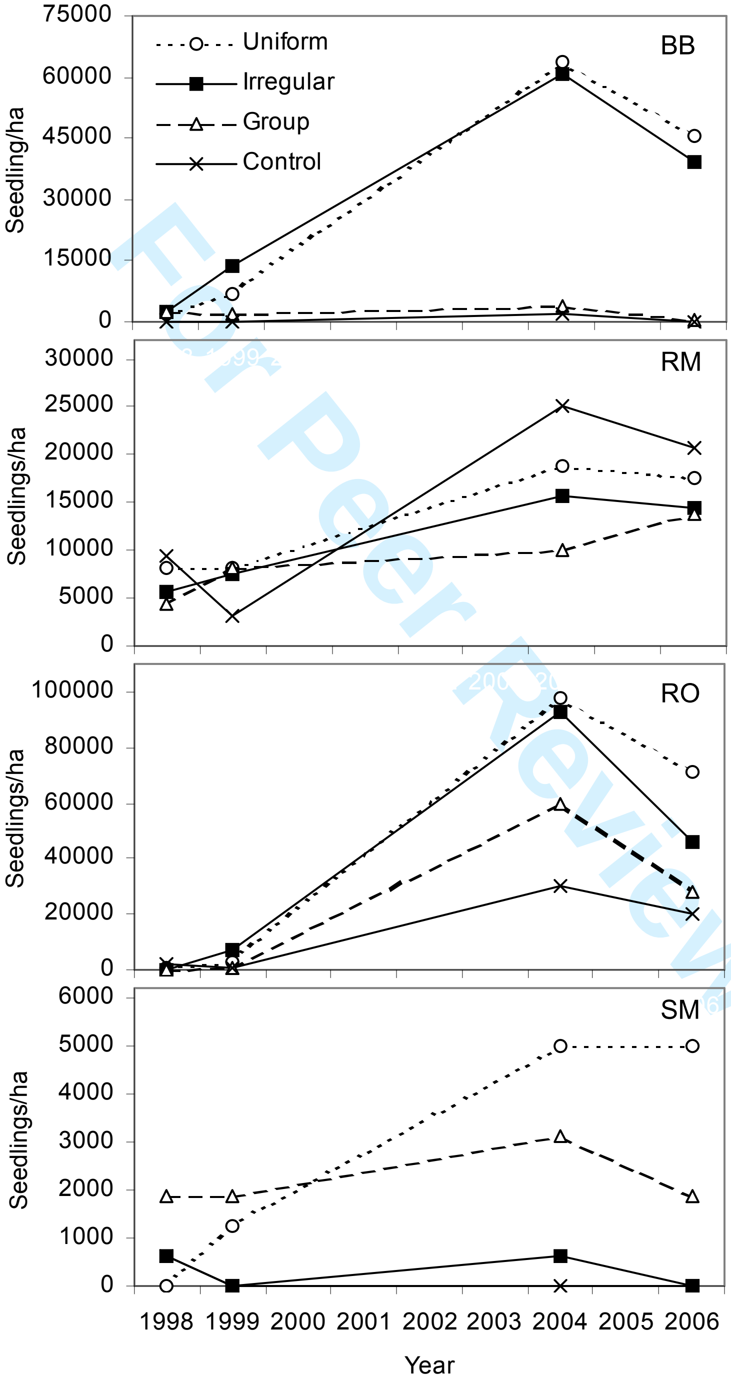

Mean height (cm)
250
200
150
100
50
0
Uniform
Irregular
Group
Control
a
b
c
d
a
a
b
b
a
ab
b
b
Max. height (cm)
500
400
300
200
100
0
a
b
c
d
a
a
b
b
a
b
ab
b
Log Basal area (m 2 /ha)
100.00
10.00
1.00
0.10
0.01
0.00
a
b
c
d
a
a
b
b
a
a
a
b
RM sprout
BB
RM
RO
SM
Species

Figure 3.



Uniform
Irregular
Group
Control
BB
Seedling/ha
75000
60000
45000
30000
15000
0
RM
Seedlings/ha
30000
25000
20000
15000
10000
5000
0
RO
Seedlings/ha
100000
80000
60000
40000
20000
0
SM
Seedlings/ha
6000
5000
4000
3000
2000
1000
0
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year