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RESEARCH ARTICLE

Maintaining a Pine Legacy in Itasca State Park

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ABSTRACT: Itasca State Park, located in the northern central portion of Minnesota, is challenged with maintaining a pine forest covertype, yet regeneration failures may allow much of the park to succeed to northern hardwoods. Efforts to improve pine regeneration and growth have included deer exclosures and prescribed burning to reduce competing vegetation. We revisited Itasca's Mary Lake deer exclosure 66 years after establishment to compare stand development, structure, and white pine (*Pinus strobus* L.) regeneration and growth with that of adjacent plots that have been: (1) untreated and (2) recently repeatedly under-burned. Overstory structure and composition was similar among all three treatments, and mid- and understory structures were similar in the treatments subject to deer browse. Sapling and midstory white pine were only present in the exclosure. White pine regeneration was present in all treatments and most abundant in the burned treatment, but was restricted to the smallest height class and consistently overtopped by the shrub layer. Regeneration, sapling, and midstory layer tree densities were highest within the deer exclosure, as was white pine height growth. The untreated plot lacked young pine and will likely succeed to northern hardwoods with a shrub understory. The three-fire sequence of the burned treatment increased the abundance of white pine regeneration at this site, but may require additional measures to control competing vegetation to allow that regeneration to ascend into the sapling layer.

Index terms: deer exclosure, prescribed fire, regeneration, white pine

MAINTAINING PARK LEGACIES

Itasca State Park, located in the northern central portion of Minnesota, was established in 1891 in part to protect remnant stands of virgin red pine (*Pinus resinosa* Aiton) and Eastern white pine (*P. strobus* L.), and maintaining mature pine forests continues to be a primary management objective (Webb et al. 2001). Although park establishment reduced the loss of mature overstory pine from timber harvest, mortality of older pine trees due to windstorms (Webb et al. 2001; Webb and Scanga 2001) and bark beetles (*Ips*) (Santoro et al. 2001) could eradicate existing red pine stands within 150 years (Kurmis 1985). Further, no new pine stands have become established to replace the older forests as they decline (Hansen et al. 1974; Peet 1984; Kurmis 1985; Webb et al. 2001). Instead, shade-tolerant tree species such as red maple (*Acer rubrum* L.), hophornbeam (ironwood, *Ostrya virginiana* (Mill.) K. Koch), and basswood (*Tilia americana* L.) have recruited into pine stands (Peet 1984; Kurmis 1985). Although existing young pine should persist for another one to two hundred years regardless of successional changes in the understory (Peet 1984; Kurmis 1985), in the absence of regeneration, older pine stands are expected to mostly succeed to northern hardwoods within a matter of decades (Hansen et al. 1974). The regeneration failure of pine within the park is, therefore, an issue of critical management importance and has been previously attributed to factors including the cessation of fire (suppressed since 1920), pressure from deer browsing, and the secondary implications of each (e.g., light competition) (Hansen et al. 1974; Peet 1984; Kurmis 1985; Webb et al. 2001). A number of other factors are thought to affect pine regeneration in this region, such as disease agents (e.g., *Diplodia* = *Sphaeropsis* blight affecting red pine), infrequent seed crops, and a narrow regeneration niche (Kershaw 1993; Gilmore and Palik 2006). The current study only addresses the direct and indirect effects of fire and deer browsing.

The region in which the park lies had a long pre-settlement history of fire (Spurr 1954; Frissell 1973; Clark 1990), which has been linked to a long regional history of dominance by red pine, mixed with white pine to a various degree (Hansen et al. 1974). Between ca. 1920 and 1995, however, there was virtually no fire within the park due to suppression efforts (Spurr 1954; Frissell 1973). Several experiments and demonstration plots have been established within the park to determine the effectiveness of using prescribed burning to stimulate pine reproduction. Although earlier efforts failed in this regard (Hansen et al. 1974), an aggressive program of prescribed fire was initiated in the past decade to restore the natural disturbance regime (Webb et al. 2001). This program has created a diversity of burned conditions within the park, permitting continued exploration of the potential utility of prescribed fire for creating conditions conducive to pine regeneration.

Historically, the park has also experienced substantial fluctuations in deer densities and hence browsing intensity. Between 1920 and 1945, when the park served as a game refuge, deer browsing of pine regeneration was intense (Ross et al. 1970). Although hunting dropped the deer population to near zero in 1945, the population rebounded and browsing confined many pines to the seedling layer and precluded the accession of seedlings into the sapling and overstory layers (Ross et al. 1970). This is a common repercussion for browse-favored species like white pine (Horsley et al. 2003; Rooney and Waller 2003). In other regions, after browsing is eliminated, some browse-sensitive tree species have been able to reestablish seedlings within a decade and even attain size distributions typical of all-aged forests after several decades (Anderson and Katz 1993; Anderson et al. 2002). This trend can be examined within the park within historically established deer exclosures.

The historic construction of fenced exclosures to prevent deer browse, although enabling established pine to increase in height growth, did not led to regeneration of red pine (Ross et al 1970; Steingraber 1989). Now that we have a better understanding of the ecological requirements for red pine germination and seedling survival, it is clearer that red pine regeneration is in fact unlikely to become established within mature pine stands in the park in the absence of considerable disturbance (coincident with good seed years, Farnsworth 2002), which is required both for seedbed conditions and to provide sufficient light for this shade intolerant species (Ahlgren 1976; Kershaw 1993; McRae et al. 1994). Armed with this knowledge, park staff now look to convert existing hardwood stands to red pine following harvesting, rather than attempting to regenerate red pine under existing canopies (B. Marty, ecologist, pers. comm. 11/12/08). However, mid-tolerant white pine has a much greater potential to establish under the existing old red and white pine overstory and, in fact, white pine seedlings are not uncommon in the park. Sustained height growth in the face of deer browse and competing vegetation, however, has not been achieved (Ross et al. 1970; Hansen et al. 1974). In light of policy considerations making a reduction in deer density unlikely, white pine height growth must be approached from another angle.

Itasca State Park management opted in the late 1990s for a program of extensive prescribed understory surface fire to restore the natural disturbance regime, with an important objective relative to the pine overstory of creating the conditions necessary to promote white pine regeneration under the existing pine canopy. Because previous experiments using prescribed fire indicated that single fires favor root-sprouting shrubs, whereas multiple fires might prepare the seedbed and deplete the root reserves of competitors (Hansen et al. 1974; McRae et al. 1994), many areas of the park have been burned multiple times. This program has shown promise for improving light conditions for pine regeneration and growth by reducing understory competition (Webb et al. 2001). We hypothesized that this understory burning program would also have substantial impacts on forest structure, and we took advantage in our sampling of the contiguity of one of the burning areas to an existing historical deer exclosure. This allowed us to compare the structure and composition of the overstory, understory, and regeneration layers in three plots within the same stand: (1) the historic deer exclosure, (2) an adjacent area that had been underburned multiple times in recent years, and (3) an adjacent untreated "control" area. Using diameter and height distributions and spatially-explicit analysis tools, we examined the structure of each plot and characterized the impacts of these treatments on stand development at this site.

SITE AND METHODS

This work applies to an area just to the east of Mary Lake in the central eastern portion of Itasca State Park in north central Minnesota (Figure 1), which is characterized by a temperate continental climate and sandy calcareous soils derived from glacial outwash within a morainic landform (Hansen et al. 1974). Fire scars indicate an historic pattern of frequent fire in the area around Mary Lake, averaging only 20 years between the eight fires that occurred between 1712 and the onset of successful fire suppression in 1920 (Spurr 1954; Frissell 1973). Although much of the surrounding area was composed of young early successional hardwood forest with an occasional mature red pine as of 1880, the area east of Mary Lake contains a remnant old-growth red and white pine forest (Spurr 1954). Our sampling took place within this stand, a portion of which has been dated to 1740 (Ross et al. 1970).

We established three adjacent permanent plots (Figures 1, 2) within this old-growth stand in 2003 (47°11'02.51-02.79" N; 95°09'42.10-43.67" W). The first plot contained the entirety of a 1.0 ha deer "Exclosure" that had been established in 1937 through the construction of a 2.1 m tall, 30-cm mesh wire fence (Steingraber 1989). At the time of establishment, 66 years prior to sampling, 1-2 yr old white pine regeneration in the Exclosure was described as "sparsely scattered throughout the plot" (Ross et al. 1970). Although at that time, ten 0.04 ha regularly spaced plots within the Exclosure were scarified, there were no significant effects on pine recruitment four years after establishment nor in overall tree species composition or density as of 1984 (Steingraber 1989). Given these results, and the fact that scarification does not necessarily increase survival of white pine under closed canopies (Cornett et al. 1998), we believe this early manipulation to have had a negligible influence in the current study. The Exclosure fence has also been shown to have no impact on small mammal densities (Steingraber 1989) and, thus, herbivory from these sources is likely comparable among the three plots.

Because of limitations on available forest of homogeneous composition and treatment, the two other treatments were sampled in 0.5-ha plots. An unmanaged "Untreated" plot was established directly to the east of the Exclosure and a "Burned" plot was established directly to the south of the Exclosure (Figure 1). The Burned plot had been treated with low-intensity prescribed surface fire in the late spring/early summer

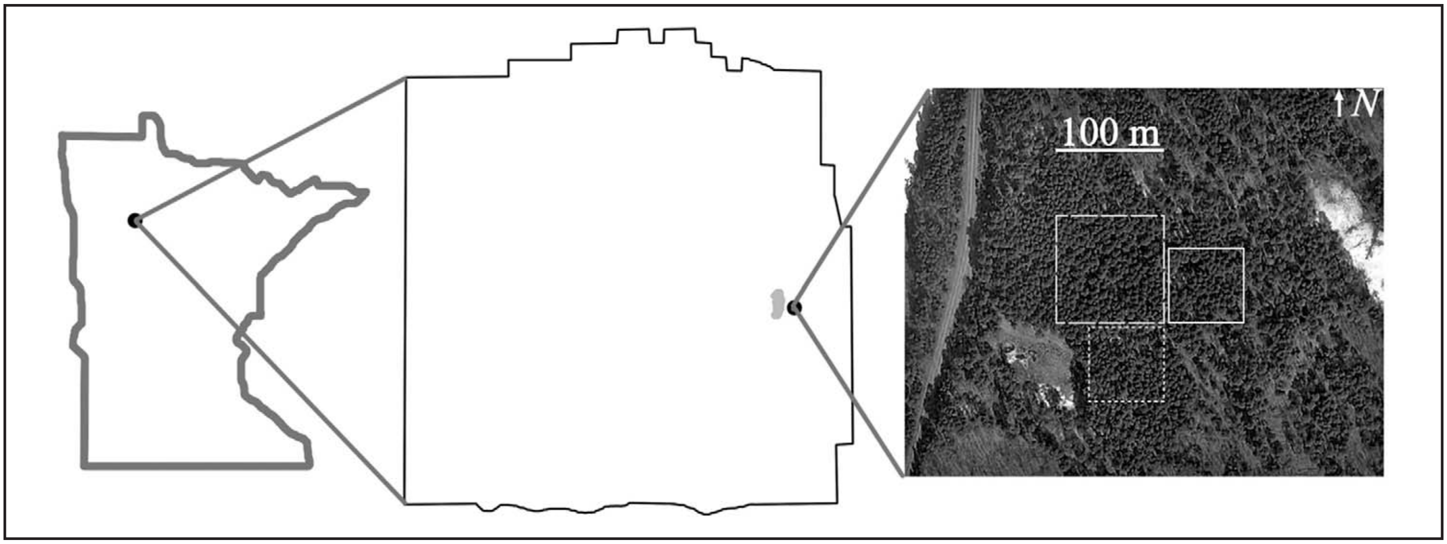

Figure 1. Itasca Park lies in the northern central portion of Minnesota. Sampling took place in a ca. 260-year old red pine stand to the east of Mary Lake in the eastern central portion of the park. A 0.5-ha Untreated control plot (solid line) and a 0.5-ha Burned plot (dotted line) were placed adjacent to the 66-year old 1.0-ha deer Exclosure (dashed line). Plot sizes were limited by a) the size of the original deer exclosure and b) the area of homogeneous forest around the exclosure belonging to each of the two treatments.

of 1997, 1999, and 2001, which did not result in overstory mortality. Although care was taken to ensure that the fire did not spread into the adjacent exclosure, there is no indication that these fires were more or less intense than other prescribed fires used in the park, which were generally of low intensity (Itasca State Park burn records 2001, Snow 1999). Detailed records on the intensity and duration of each fire are not available (C. Handrick, resource specialist, pers. comm. 12/8/08).

Each plot was stem-mapped using a Criterion laser in the summer and fall of 2003. The position of each live tree greater than 2 cm in diameter at breast height (dbh) was recorded and slope-corrected distances and azimuths were converted to Cartesian coordinates. Species, dbh, and crown class (dominant, co-dominant, intermediate, or

Figure 2. Visual examination of the plots reveals a stronger sapling and understory tree layer (including small white pine) within the deer Exclosure (left) and taller understory shrubs in the Untreated plot (center) compared to the relatively open Burned plot (right).

suppressed) were recorded for all mapped trees. To evaluate the impact of the prescribed burns on structure, dead trees were also mapped and tallied in the Untreated and Burned plots.

Regeneration was assessed in each plot within equidistant systematically placed and mapped 2-m radius subplots; 16 in the Exclosure and nine each in the smaller Burned and Untreated plots. In each subplot, the density (i.e., number of stems) of each woody species (trees and shrubs) less than 2 cm in dbh was recorded for each of five height classes: 0-10, 11-50, 51-100, 101-137, and > 137 cm (i.e., over breast height).

Overstory diameter distributions were based on a 2-5 cm class and then 5-cm increments up to 55 cm and > 55 cm dbh. Diameter distribution graphs were plotted for all species with at least 50 stems/ha in one of the plots. The regeneration layer was summarized as the average density (stems/ha) of each species across all subplots in a plot for each of the five height classes. Height class distribution graphs were plotted for all species with a greater than 25% frequency of occurrence across all 34 subplots.

The Cartesian coordinates for each tree were used to calculate Ripley's K functions (Ripley 1977), which estimate spatial dependence between points at a range of spatial scales and whose effectiveness at capturing spatial patterns has been recently reconfirmed in a comparison of two-dimensional spatial tools (Li and Zhang 2007). Univariate K(d) (Moeur 1993) was used to investigate the two-dimensional distribution of all tree species, pines, non-pines, and red maple by 5-cm diameter classes. Bivariate K_{12}(d) (Diggle 1983) was used to test for spatial independence of paired groups, including overstory pines vs. understory and midstory red maple and pairs of 5-cm diameter classes. Red maple was given special attention because of the abundance of this shade-tolerant species in the regeneration layer. The type of pattern is reported using L(d), a square root transformation of K(d) that stabilizes the variance. Negative L(d) values indicate regularity, inhibition, or repulsion, and positive values indicate clustering or attraction (Moeur 1993). Departures from a random distribution were evaluated with Monte Carlo tests that compared the observed L(d) distribution to values from multiple spatial patterns generated from a Poisson model. In all cases, 200 spatial patterns were generated in each Monte Carlo simulation to define point-wise 95th percentile confidence boundaries at distances from 0 to 25 m by 0.5-m intervals.

RESULTS AND DISCUSSION

Overstory Structural Conditions

Having constituted a single continuous stand of forest at the time of the first treatment implementation in 1937, the overstory layer was presumably homogenous among the three plots. In 2003, all dominant trees in all three plots were pine, with only a few scattered non-pine co-dominants (Figure 3), including a handful of *Picea glauca* (Moench) Voss and *Betula papyrifera* Marsh. var. *papyrifera*. The densities (212-256 trees/ha) and basal areas (35-41 m^2/ha) of overstory pine were similar among all three plots. All plots exhibited a unimodal diameter distribution for red pine (Figure 4), shifted to the right due to the virtual absence of saplings. The homogeneity of overstory structure not only reflects a

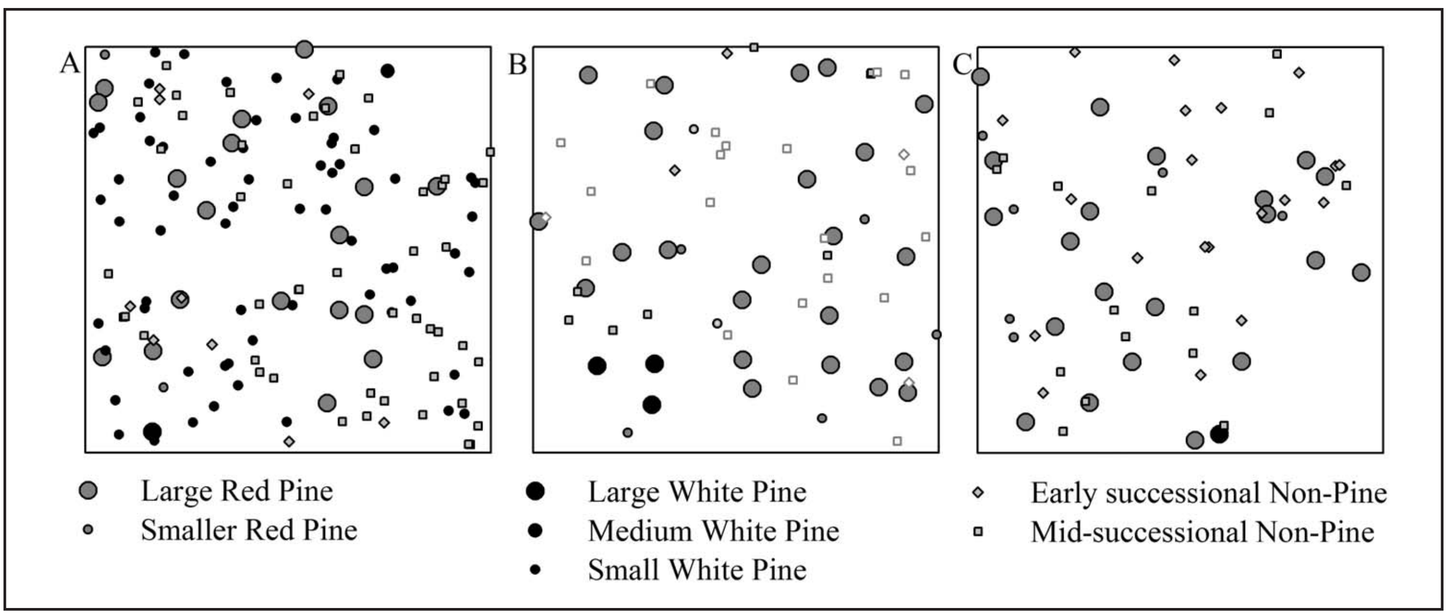

Figure 3. Stem-map close-up of a 0.1-ha portion of each plot, showing the exact spatial position of each tree. The overstory (large red and white pine) structure is very similar across plots, reflecting uniformity of initiation and stand history. The understory of the Exclosure (A), however, has many small white pine and a higher density of non-pines than the Untreated plot (C). Density in the Burned plot (B) has been further reduced through the mortality of understory trees (white filled symbols indicate recent mortality). Early successional non-pine included *Betula papyrifera*, *Fraxinus americana, Populus grandidentata*, and *Quercus rubra*. Mid-successional non-pine included *Abies balsamea*, *Acer rubrum*, *Acer saccharum*, *Ostrya virginiana, Picea glauca*, *Quercus macrocarpa*, and *Tilia americana*.

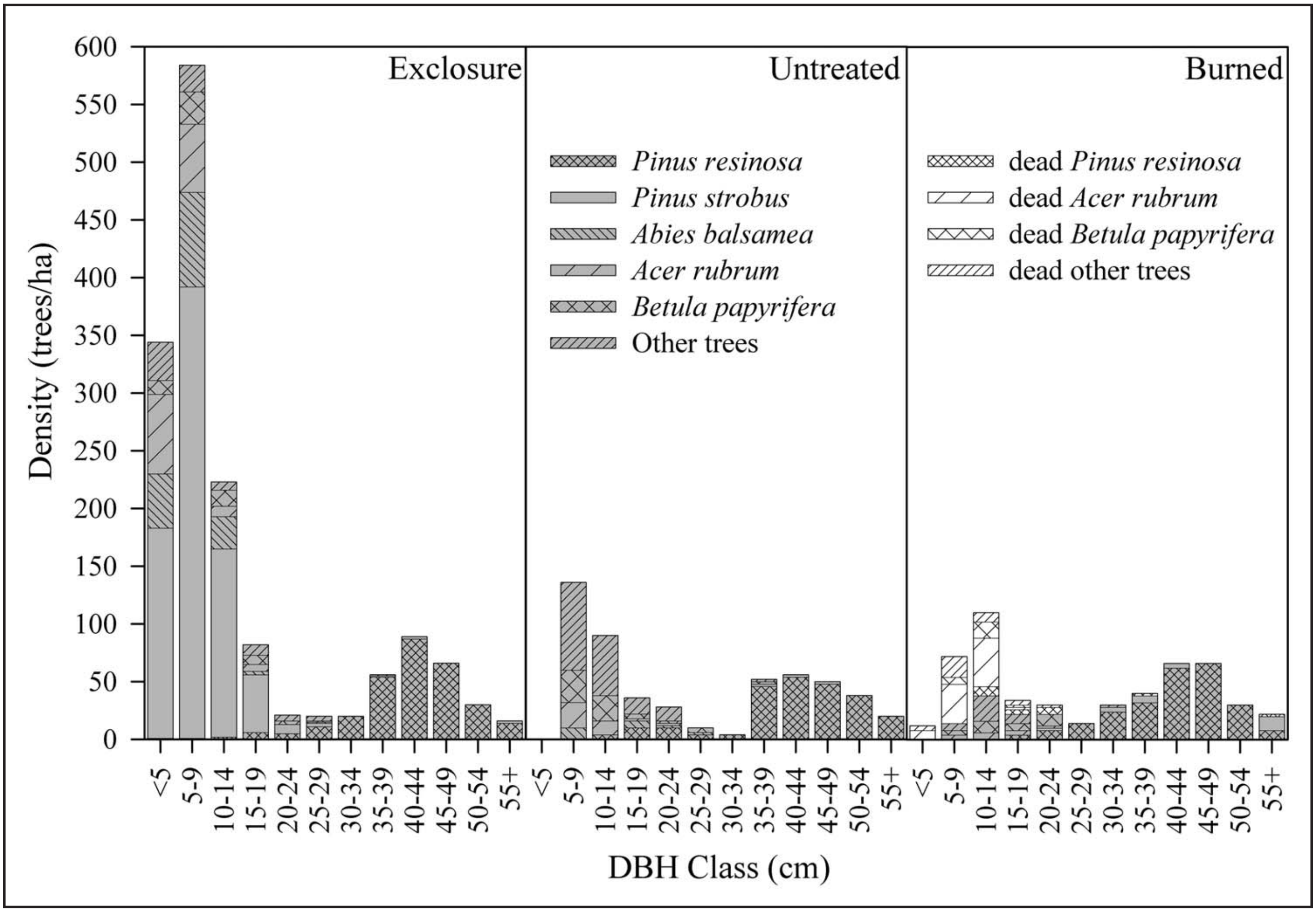

Figure 4. Density of trees > 2 cm in diameter at breast height across twelve diameter classes. Numerous recently dead trees were found in the Burned plot. The largest diameter classes are dominated by pine in all treatments, but small pine are absent from both the Untreated and Burned treatments. Other trees included *Acer saccharum*, *Fraxinus americana*, *Ostrya virginiana*, *Picea glauca*, *Populus grandidentata*, *Quercus macrocarpa*, *Quercus rubra*, and *Tilia americana*.

common pre-treatment history, but indicates that the factors affecting overstory structure continued to be consistent across plots over the past 66 years since the establishment of the exclosure. A right-shifted unimodal distribution is typical of older stands of disturbance-origin tree species (e.g., Zenner 2005), including red pine (Frelich and Reich 1995), due to a failure to self-replace under low light conditions. In contrast to some aggregation of smaller size classes, overstory pine greater than 35 cm in diameter (i.e., dominant and co-dominant canopy trees) showed a random spatial pattern with univariate Ripley's *K,* and the bivariate analysis indicated general repulsion at all spatial scales. This is in keeping with previous findings that density-dependent competition results in a more regular or even spatial pattern (Antonovics and Levin 1980; Kenkel 1988; He and Duncan 2000).

The midstory layers in the unexclosed plots also reflected a similar disturbance history over most of the past 66 years, during which fire was absent but deer browse prevalent. Subsequently, there was correspondence between the density (160-180 trees/ha), basal area (3.3-3.5 m^2/ha), diameter distribution (Figure 4), and species composition of the live and dead trees of the midstory layer (intermediate and suppressed trees 10-30 cm in diameter) in the Untreated plot and the Burned plot. In keeping with the natural successional trend for old-growth red and white pine forests in this region (Kittredge 1934; Frissell 1973; Peet 1984), the midstories were composed of mostly mid-successional species, primarily hardwoods such as *Acer rubrum*, *Acer saccharum* Marsh., *Ostrya virginiana, Quercus macrocarpa* Michx., and *Tilia americana*, and completely lacked pine. There was no evidence of density-dependent competition (i.e., no dispersion) among understory or midstory trees. All understory trees and non-pine midstory trees were aggregated at all spatial scales, while all midstory trees showed aggregation at larger scales (20-25 m) in the Exclosure than in the Burned and Untreated plots (3-13 m). Although purely speculative, the smaller scale of aggregation in the browsed plots is consistent with the possibility of historic local patches of vegetation that may have protected tree seedlings from deer browse (c.f., Anderson et al. 2002). Midstory and understory pine were aggregated at very small (1-7 m) and very large (21-25 m) scales in the

Exclosure, which likely reflects limited and patchy dispersal (Kershaw 1993).

White Pine Height Growth and Stand Development Under the Three Treatments

The density of midstory and understory trees was highest in the Exclosure, and the Exclosure had regenerating smaller diameter white pine that were absent from the other treatments (Figure 4). Given reports of continued deer browse to white pine outside the exclosure (Steingraber 1989; Webb et al. 2001), the conclusion can be drawn that this enhanced establishment and height growth was afforded by the protection from deer browsing. The suppression of white pine by deer browsing is best indicated by the absence of understory or midstory white pine in the browsed Untreated (and Burned) plot, compared to the over 200 small white pine within the Exclosure (Figure 4). The abundance of white pine seedlings across the treatments (Figure 5) suggests that germination may not be the bottleneck, but rather the ability to ascend above competing vegetation and the browse line (Ross et al. 1970; Steingraber 1989).

Given the protection afforded by the deer fence, red pine saplings might also be expected to be more abundant within the Exclosure. Red pine seedlings and small saplings present at the time the Exclosure was established, however, have long since either perished or ascended into the midstory and have not been replaced. The Exclosure contained 47 red pine saplings in 1946 and 79 in 1969 (Ross et al. 1970) but only 10 remain as of 2003. Of 427 red pine found in the exclosure in 1969, 294 were overstory trees (Ross et al. 1970). As of 2003, the overstory had changed little (287 red pine) but the total number of red pine had dwindled to 297. The spatial arrangement of trees provides some insight into this dynamic. First, there was some evidence that the environmental space was partitioned into different neighborhoods on the basis of size classes (after Dovčiak et al. 2001), in that midstory trees (15-20 cm dbh) and large overstory trees (35-50 cm dbh) repulsed one another at small to medium scales (2-12 m). Second, the minimum scale of aggregation increasing with

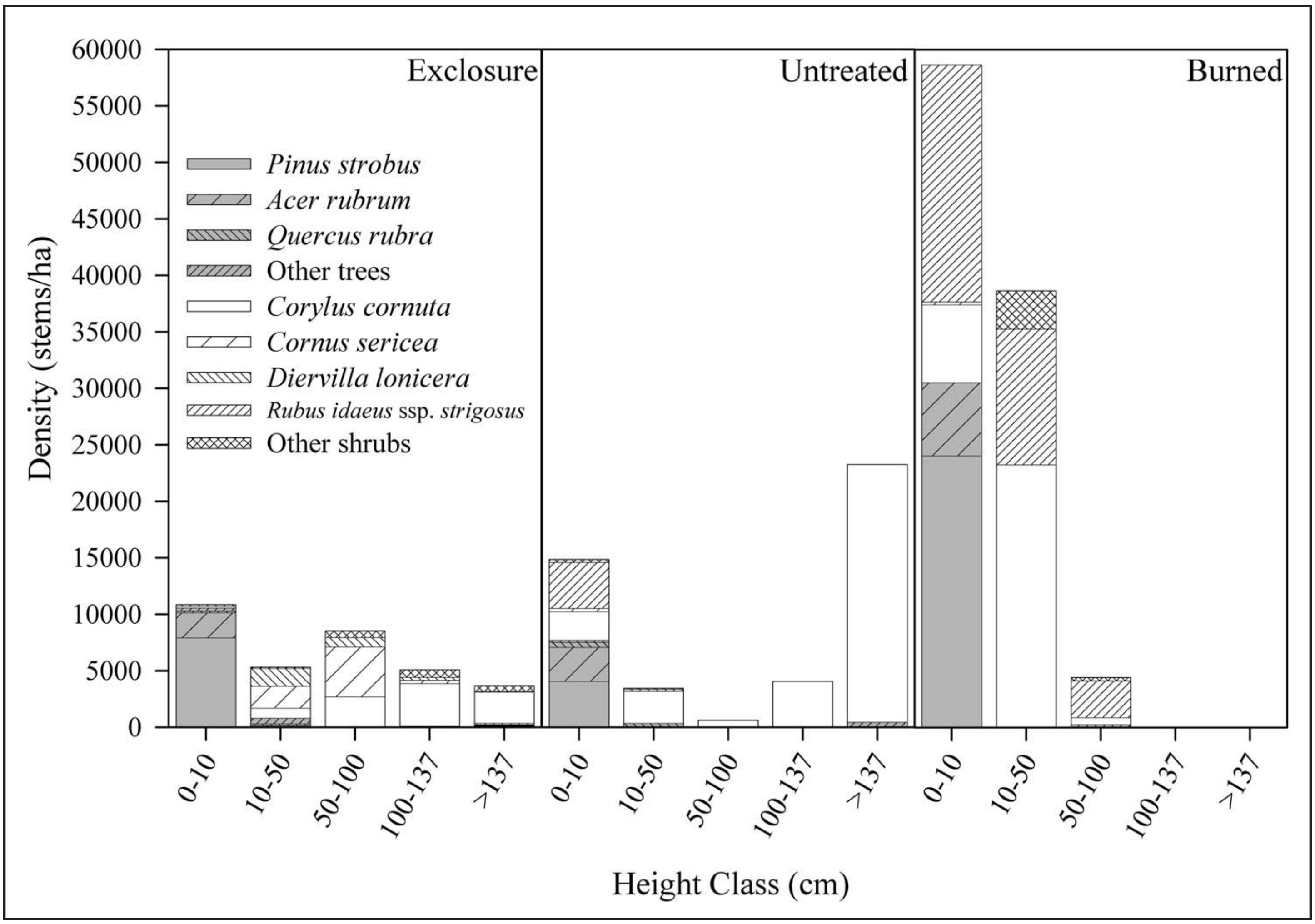

Figure 5. Average density of woody vegetation < 2 cm in diameter at breast height across five height classes. White pine seedlings (solid grey) were most abundant in the Burned treatment, but so too were beaked hazel (solid white) and raspberry (tight right slashed white). All pine regeneration was restricted to the lowest size class. Other trees included *Abies balsamea*, *Acer saccharum*, *Acer spicatum*, *Betula papyrifera*, *Fraxinus nigra*, *Ostrya virginiana*, *Prunus virginiana*, and *Quercus macrocarpa*. Other shrubs included *Amelanchier* spp., *Cornus rugosa*, and *Zanthoxylum americanum*.

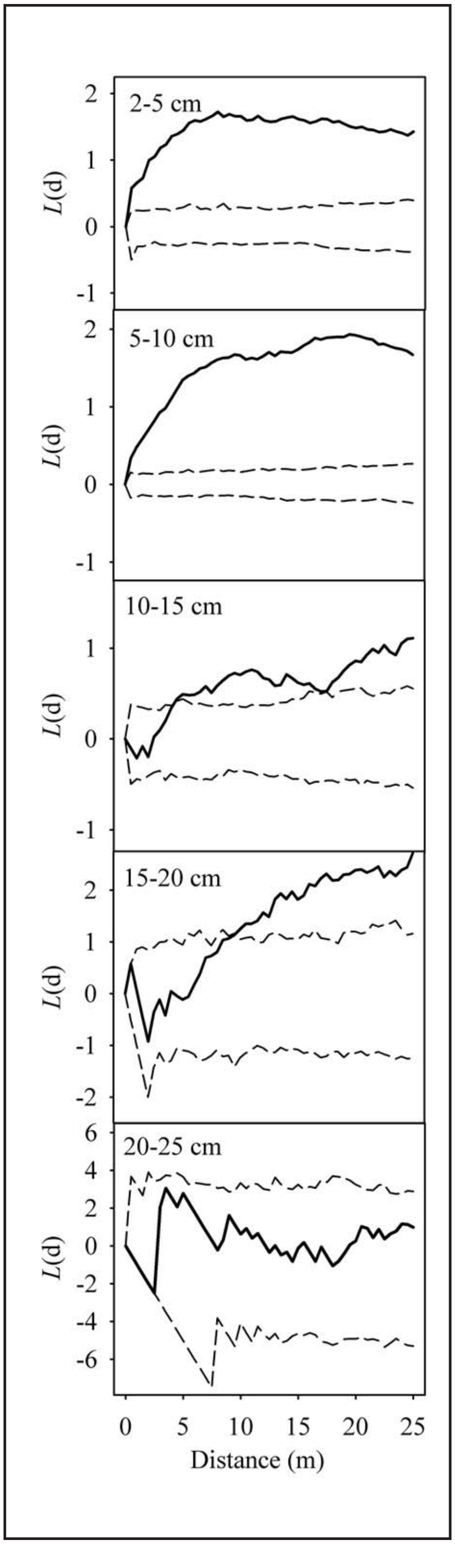

Figure 6. Ripley's *K* point pattern analysis of all trees within the Exclosure by diameter class, plotting the square root transformation *L*(d) at various scales. Dashed lines are the 95th percentile confidence bands. Note that the scale at which *L*(d) becomes significant (i.e., lies outside of the bands) increases with increasing diameter class and thus that the minimum scale of aggregation increases with increasing tree size.

increasing tree size in our study (Figure 6) was also found by Dovčiak et al. (2001) in white pine. Subsequently, the average tree-to-tree distance for trees of the same size class increased with increasing size class (from 1.8 m for 5-10 cm trees to 11.5 m for 25-30 cm trees). These findings suggest strong density-dependent self-thinning followed by substantial mortality of suppressed trees.

We had, therefore, expected that the proportion of shade-tolerant tree species would commensurably increase within the Exclosure. Tree species richness did not vary among treatments (10-13 species/plot), and random bivariate associations provided no evidence for interspecific competition between overstory red pine and the most abundant non-pine understory and midstory species, red maple. There were, in fact, more midstory and understory shade- and mid-tolerant trees in the Exclosure (89% by density) than in the Untreated plot (50%). However, given that 97% of these in the Exclosure were white pine, this may again reflect the reduction in browsing pressure more than a potential reduction in light. Similarly, the higher density of shade tolerant shrubs, particularly beaked hazel (*Corylus cornuta* Marsh.), in the Untreated plot than in the Exclosure (Figure 5) may reflect the relative tolerance of this species to deer browse. Few other species had ascended into the tall regeneration layer (> 50 cm in height) and, although lacking compensatory growth, beaked hazel has been found to be highly tolerant of deer browse and, thus, readily capable of ascending above the browse line (Steingraber 1989).

Although species richness in the regeneration layer was identical among treatments (all three averaging 5, standard deviation 1), two substantial differences in this layer exist between the Untreated and the Burned plots (Figure 5). First, tall regeneration was zero in the Burned plot, presumably as a result of post-fire mortality. The prescribed burns also seemingly killed a number of understory trees. Compared to zero dead trees found in the Untreated plot, fully a third of the trees in the Burned plot were dead at the time of sampling (Figures 3, 4). All of the recent mortality in the Burned plot was of small diameter and/or thin-barked trees that tended to be aggregated at all spatial scales, as is typical of patchy low-intensity surface fires (Johnson 1991). Second, the density of small regeneration, and particularly of white pine, was considerably higher in the Burned plot. Two anticipated consequences of the prescribed fire may be linked to this finding, both of which contribute to improved pine germination conditions: soil disturbance and increased light due to shrub and small tree mortality (McRae et al. 1994). Thus the three-fire sequence in the Burned plot appears to have boosted white pine seedling establishment at this site.

Future Outlook near Mary Lake

The abundant white pine regeneration in the Burned plot, as in the other plots, was restricted to the smallest (< 10 cm) height class (Figure 5), despite two-year growth rates of 20 cm in white pine regeneration on a similar site (and under a pine canopy) in the region (E. Zenner, unpubl. data). Further, the primary competing shrubs (beaked hazel and raspberry (*Rubus idaeus* L. *ssp. strigosus* (Michx.) Focke)) already overtopped the white pine regeneration (Figure 5), which may have implications for white pine seedling survival (Cornett et al. 1998). Even if the deer browsing pressure was diluted due to the increased abundance of white pine regeneration, light competition from the shrub layer will likely still preclude the ascension of white pine into the sapling layer. Browse tolerance becomes a critical factor for growth rates, and thus species composition, in the presence of deer (Ammer 1996) due to both the direct impact of browse on preferred species and the indirect impact of selectively favoring shade-casting browse-tolerant species (Steingraber 1989; Horsley et al. 2003; Rooney and Waller 2003). This would serve to restrict white pine seedlings to the lowest height classes. Thus, although setting the beaked hazel back, even a three-fire sequence does not appear to have been sufficient to exhaust the root reserves of this species at this site.

Light competition appears to be a limiting factor for white pine growth in the unbrowsed Exclosure as well, where white pine regeneration was also limited to the smallest size class. Although the presence of white pine in the sapling and midstory layers indicates that conditions were once conducive to ascension above the seedling layer, now that these layers have filled in, they provide considerable shade to the understory. Thus, the successful ascension of white pine regeneration in past decades may now preclude white pine regeneration height growth. The establishment of the sapling and midstory layers, however, has likely ensured the perpetuation of the pine legacy in this plot. White pine is capable of enduring decades of suppression followed by growth following release, even multiple times (Abrams and Orwig 1996). As the overstory red pine trees die, either singly or simultaneously (e.g, windthrow), the sapling and midstory white pine layer should ascend into the canopy in the Exclosure, maintaining a pine overstory. Mortality in the Untreated and Burned plots, however, will likely result in succession to a northern hardwoods forest with an abundant beaked hazel understory.

Future Outlook for White Pine Regeneration in Itasca State Park

White pine is an adaptable species with a broad distribution and was historically widespread and variably abundant (Jones 1992; Abrams 2001). It germinates on seedbeds ranging from mineral soil to heavy litter and has good seed crops every 3-10 years (Ahlgren 1976). White pine seedlings, in fact, are often abundant within the park (Webb et al. 2001). There are, however, a variety of obstacles facing the establishment, growth, and survival of white pine (Jones 1992). Based on the literature and our current findings, a best-case scenario for regenerating white pine under the existing pine canopies in Itasca State Park would entail: (1) establishment on thin litter layers (Kershaw 1993), (2) early growth in the absence of deer and small mammal herbivory (Saunders and Puettmann 1999; Anderson et al. 2002), (3) a relatively open canopy but limited understory competition (Saunders and Puettmann 1999) to provide light levels of 20-50% for sufficient growth (Logan 1959) yet protection from blister rust (Stearns 1992), followed by (4) release through a more open canopy after saplings are > 6 m tall and out of the white pine weevil zone (McRae et al. 1994). Because shade tolerance also allows white pine to survive, albeit suppressed, for decades and then increase growth after release (Puettmann and Saunders 2000; Krueger et al. 2007), established white pine saplings should be able to survive in the understory until overstory mortality provides an opportunity to ascend into the canopy.

Although prescribed fires within the park have been lower in severity than historic wildfires and generally insufficiently intense to eliminate understory competition from shallow-rooted shrubs such as hazel (Snow 1999), our findings suggest they may be able to reduce litter thickness and reduce competition long enough to promote germination. Park officials may, therefore, have success with periodic continued underburning of existing pine stands to provide for abundant white pine germinants. Once established, control of competing vegetation would then be critical to enable white pine to ascend above both the browse line and shade-casting shrub layer. In areas with relatively little competing vegetation, we concur with Webb et al. (2001) that fencing areas with strong white pine reproduction would likely maintain a pine legacy. In areas that have high shrub and understory hardwood tree cover, some form of competition control may need to be considered by park staff. Brushing (i.e., physically cutting) competing vegetation in this region has not always met with success (e.g., Powers et al. 2008), whereas herbicides have sometimes been proven effective at controlling vegetation competing with white pine regeneration (Hansen et al. 1974). The question remains whether or not, now that an extensive portion of the park has been underburned, a strong seed crop could lead to sufficient white pine germination to sufficiently overcome browsing pressure for enough white pine seedlings to ascend into the sapling layer to maintain a pine covertype.

Valuable lessons could still be learned through future research at this site in at least four areas. First, what are optimal combinations of number of prescribed fires and years until a good seed crop? If an area has been burned the year before a good seed crop, is a single fire sufficient to promote germination and establishment? This question may be able to be addressed using existing park records over the period of the burn program. Second, what are optimal combinations of seedling density and deer browse intensity? If white pine seedling density is amply high over a large enough area, could per-tree deer browse pressure be adequately reduced to enable a sufficient number of white pine to ascend into the sapling layer? This question could be answered by controlling for deer density (or artificial clipping) within deer exclosures. Third, what is the optimal combination of intensity and timing of competing vegetation control? If white pine seedlings are already established but suppressed, could a single herbicide application sufficiently reduce competition to enable a sufficient number of white pine to ascend into the sapling layer? This question may be able to be answered by applying herbicides to competing vegetation in existing patches of high white pine seedling density. Finally, on rich, mesic sites, is a combination of control required for both deer browsing and competing vegetation? If white pine seedlings are established on sites tending toward northern hardwoods succession, can controlling for competing vegetation alone enable a sufficient number of white pine to ascend into the sapling layer or is browse protection also required? This could be addressed by applying herbicides to patches within the deer exclosures noted above.

SUMMARY AND CONCLUSIONS

This study explored structural changes occurring in forested plots within Itasca State Park that have been: (1) untreated, (2) protected from deer browse for 66 years, and (3) recently repeatedly underburned. While the overstory of all three plots was comparable, the midstory layer of the Exclosure contained a high density of mid-successional species, including sufficient white pine to likely maintain a pine overstory. In contrast, the unexclosed plots had much lower small tree densities, with many small-diameter snags in the Burned plot. Although white pine regeneration was present in all treatments, it was most abundant in the Burned plot. However, all white pine were restricted to the seedling size class. Further, competing vegetation was also much more abundant in the Burned plot and already overtopping the white pine regeneration.

In the 1.0 ha Exclosure, the established white pine sapling and midstory layer will likely ensure continuity of pine forest, albeit white pine, despite future mortality of the red pine overstory. In contrast, in the absence of intervention, the Burned and Untreated plots both appear to be on a trajectory to succeed to a northern hardwoods cover type with a strong shrub understory. It is possible that this trajectory could still be changed in the Burned plot if the existing white pine regeneration were released through herbicide control of the competing shrub layer. Further research within the park could explore the intensity and timing of using fire and herbicides to control competing vegetation and deer exclosures to reduce browsing pressure.

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