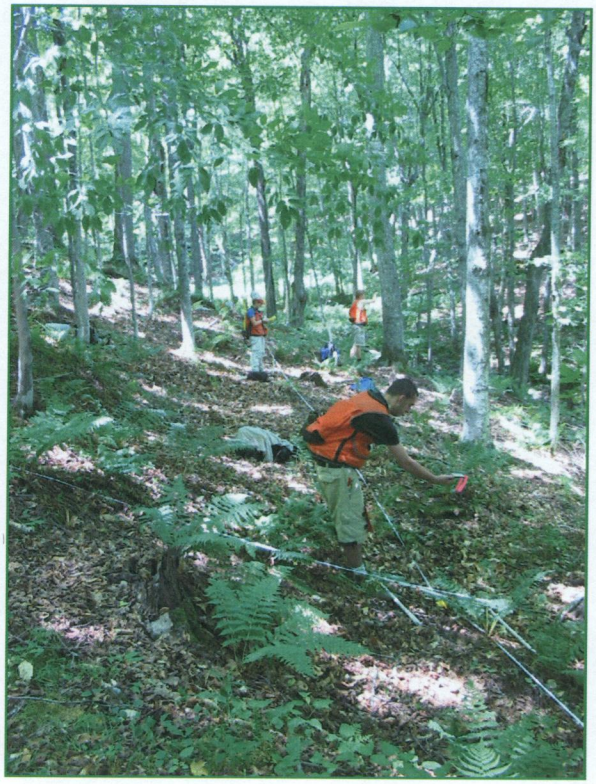
FOREST MONITORING AT THE MARSH-BILLINGS-ROCKEFELLER NATIONAL HISTORICAL PARK

2003 ANNUAL REPORT





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INTRODUCTION

The Marsh-Billings-Rockefeller National Historical Park has initiated a cooperative program with the University of Vermont, School of Natural Resources, establishing a long-term forest ecosystem monitoring system within the forested portion of the 550 acre (223 hectare) Park. The monitoring program consists of annual field data collection using a system of permanent plots distributed throughout the Park. Data are analyzed at the University of Vermont and archived both there and at the Park. This report presents preliminary results of analyses using data collected in summer 2001 during the first year of the program. Future annual reports will present data from subsequent years.

Relevance of monitoring

The Mt. Tom woodland near Woodstock, VT is one of the earliest surviving examples of scientifically informed reforestation and forest management in the United States. Early and evolving forest conservation efforts and silvicultural practices, beginning with Frederick Billings' first large scale tree plantings in 1874, left a legacy that is still very apparent throughout much of what is now the Marsh-Billings-Rockefeller National Historical Park (MBR). The establishing legislation for the Park directed that the tradition of professional forestry practiced on Mt. Tom for almost 125 years be continued by the National Park Service as an educational demonstration of forest stewardship and to preserve this cultural landscape. Places of cultural and historic significance in the forest mosaic are to be managed as "readable landscapes," maintaining the character defining features that tell this story.

The rich history of land management at Mt. Tom created an unusual variety of spatial and experiential characteristics. There are many large trees, unusual for eastern second growth woodlands; including a number of old-growth hemlocks, many greater than 300 years old; tall, graceful Norway spruces, originally planted by Frederick Billings; and old maples dating back to George Perkins Marsh and the earliest settlements on Mt. Tom. The Park represents one of the earliest examples in New England of active reforestation efforts. For instance, a number of coniferous plantations of both native and non-native species were established beginning in the 1880s and continuing through early 20th century. Today these comprise 26% (61 hectares) of the Park's area. But reforestation also occurred without planting in many areas of the forest, largely as a result of agricultural abandonment, resulting in naturally regenerated northern hardwood, hemlock, and mixed forests. In some areas this natural regeneration was augmented with scattered planting of native hardwood species, although often using non-local planting stock. Semi-natural forests represent 63% (142 hectares) of the Park. The Park's "patchy" forest mosaic reflects this history of alternate reforestation approaches and varied successional trajectories.

The Park today includes a wide diversity of stand types as well as pronounced visual contrasts and view corridors created by open pastures and fields surrounded by dense forest plantations. Visitor experience of alternating openness and enclosure is further enhanced by the 14-mile system of 19th century carriage roads winding through the forest and over Mt. Tom. As a unit of the National Park System, the forest will be managed to maintain these unique and distinctive cultural and visual qualities.

MBR has a mission that is largely unique within the National Park System: it includes active forest stewardship as well as biodiversity and ecological conservation, a mandate shared by all units of the National Park System. Meeting these twin mandates necessitates an active science program to inform management activities, such as long-term planning. The forest monitoring program is designed to achieve this goal. Monitoring helps Park managers determine the health, productivity, development, and sustainability of both plantations and semi-natural forests. It informs planning to conserve plant and animal populations and manage recreational activities, visual qualities, and cultural interpretation accordingly. Long-term challenges, such as climate change, acid deposition, spread of exotic insects and pathogens, and ever-changing public expectations of natural areas, require an adaptive approach to park management. This report presents data relevant to each of these management concerns.

Focus on succession in plantations and semi-natural forests

MBR is an ideal place to monitor and interpret long-term reforestation and recovery processes. Restoration at the property, beginning as early as 1880, involved a range of direct planting and augmented natural regeneration methods. The park bears the profound legacy of 19th century clearing and land-use, as well as the subsequent influences of evolving cultural notions about reforestation and forestry. It is a microcosm, therefore, of the human-influenced successional dynamics and recovery processes now occurring across forested landscapes in the northeastern United States.

Consequently, an emphasis of monitoring at MBR is successional development within forest stands that are representative of the Park's diversity of reforestation strategies, stand ages, silvicultural management, and plant communities. Successional development is a key measure of the long-term success or effects of the variable reforestation approaches. It is also an indicator of wildlife habitat representation (Keddy and Drummond 1996; Kruse and Porter 1994), as exhibited by the mix of successional stages (e.g. early, mid, or late-successional) and structural classes (e.g. single vs. multi-layered forest canopies). As such, it facilitates evaluation of the Park's contribution to local and regional biodiversity conservation. The monitoring program evaluates a number of specific parameters that reflect successional or stand development processes (Franklin et al. 2002; Oliver and Larson 1996). These include diameter distributions, canopy layering or vertical structure, tree species reproduction and demography, mortality rates, coarse woody debris, and understory plant community development. This report evaluates data on these and other forest metrics, providing a basis for both biodiversity conservation and timber management planning. Future reports will also evaluate tree health, for which data collection began in Year Two of this program. Growth rates will also be analyzed based on data from multiple years.

Stand development processes in plantations are a particular focus of current planning efforts at MBR. The long-term maintenance of current species composition is in question, with respect to both plantations of exotic species and plantations of native conifers established on inappropriate sites, for instance where a given species is not locally endemic. Consequently, the monitoring program is designed to contrast stand development in plantations with development in semi-natural forests. Much of the analysis presented in this report is organized in this manner.

With a substantial portion of the Park in stand conditions (e.g. ages 80 to 110 years old) approaching transition to late-successional structure and composition, it is important to monitor factors, such as diseases and insects affecting shade-tolerant tree species, that may affect that potential. The monitoring program is designed to detect such a perturbation of stand development, thereby allowing managers to plan appropriate silvicultural interventions as needed.

Much of the continuing forest stewardship in the park will involve demonstrations of sustainable forestry practices, such as logging methods that minimize disruption to wildlife and sensitive plant habitats. An adaptive management approach is critical for these purposes as well as overall resource management planning, allowing park managers to learn from past successes and failures and make adjustments as needed. Baseline monitoring is required for robust evaluation of forest management effects. Thus, the forest dynamics monitoring system is an essential component of an adaptive management approach.

Monitoring objectives

The monitoring program has several objectives. They are as follows:

1. establish a system of reference stands and permanent monitoring plots that is representative of the Park's diversity of plantations and semi-natural forest stands;

2. evaluate parameters within the following categories: a) indicators of structural and compositional development; b) tree regeneration; c) understory plant community composition; and d) forest health indicators;

3. conduct periodic plot re-measurements

4. maintain databases at the University of Vermont and MBR.

5. use statistical and data integration techniques to describe the current, near-term, and long-term attributes and dynamics of forest structure, composition, and health on the Park.

6. monitor key forest ecosystem processes, including growth, yield, and mortality; changes in wildlife habitat availability; the onset, spread, and effects of tree diseases and insect pests; and tree vigor trends and successional transitions in exotic and native timber plantations; and

7. Coordinate with existing federal, state and regional programs, such as the Vermont Monitoring Cooperative and the NPS Inventory and Monitoring Program, to monitor forest ecosystem sustainability and responses to stresses, such as airborne pollution and climate change.

METHODS

Data collection

The monitoring system is based on a statistical sample (i.e. multiple plots) within individual forest stands. However, because the Park has over 50 stands (Wiggin 1993), and because many of these are very small (e.g. < 3 ha.), it was not possible within current budgetary constraints nor, perhaps, desirable from a research stand point to establish monitoring plots in all stands. Consequently, a subset of reference stands were selected for monitoring. The procedure for selecting reference stands was to stratify the stands delineated by Wiggin (1993) by species composition, age, plantation versus semi-natural, and silvicultural management history. The largest and/or most representative examples within each strata were selected as reference stands. Sixteen reference stands were selected in this way, consisting of eight plantations and eight semi-natural stands (Figure 1).

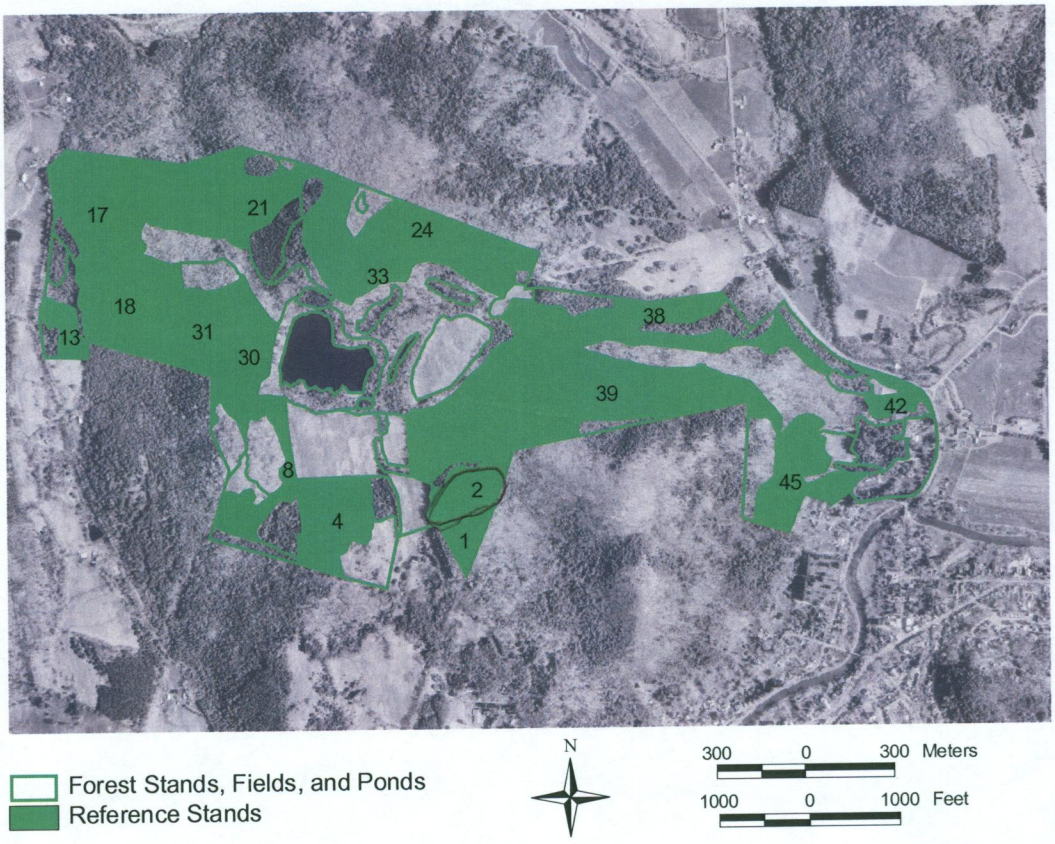


Figure 1. Reference stands selected for forest ecosystem monitoring. There are eight plantations and eight semi-natural stands. Stand identification numbers follow Wiggin (1993).

Permanent sampling plots were established within each reference stand. The number of plots in a stand is proportionate to the size of the stand, ranging from three to six plots, with the majority of stands having five plots. Stand 42 is an exception, having only one plot due to its particular dimensions; although statistical sampling was not possible it was selected for limited monitoring due to its unique combination of age and composition. A geographic information system was used to place the plots in a stratified random pattern to meet statistical sampling requirements while

ensuring even dispersion within each stand. Pre-determined plot centers were located in the field using a highly accurate Trimble Pro XRS Global Positioning System (GPS). A total of 62 monitoring plots were established in summer 2001 (Figure 2).

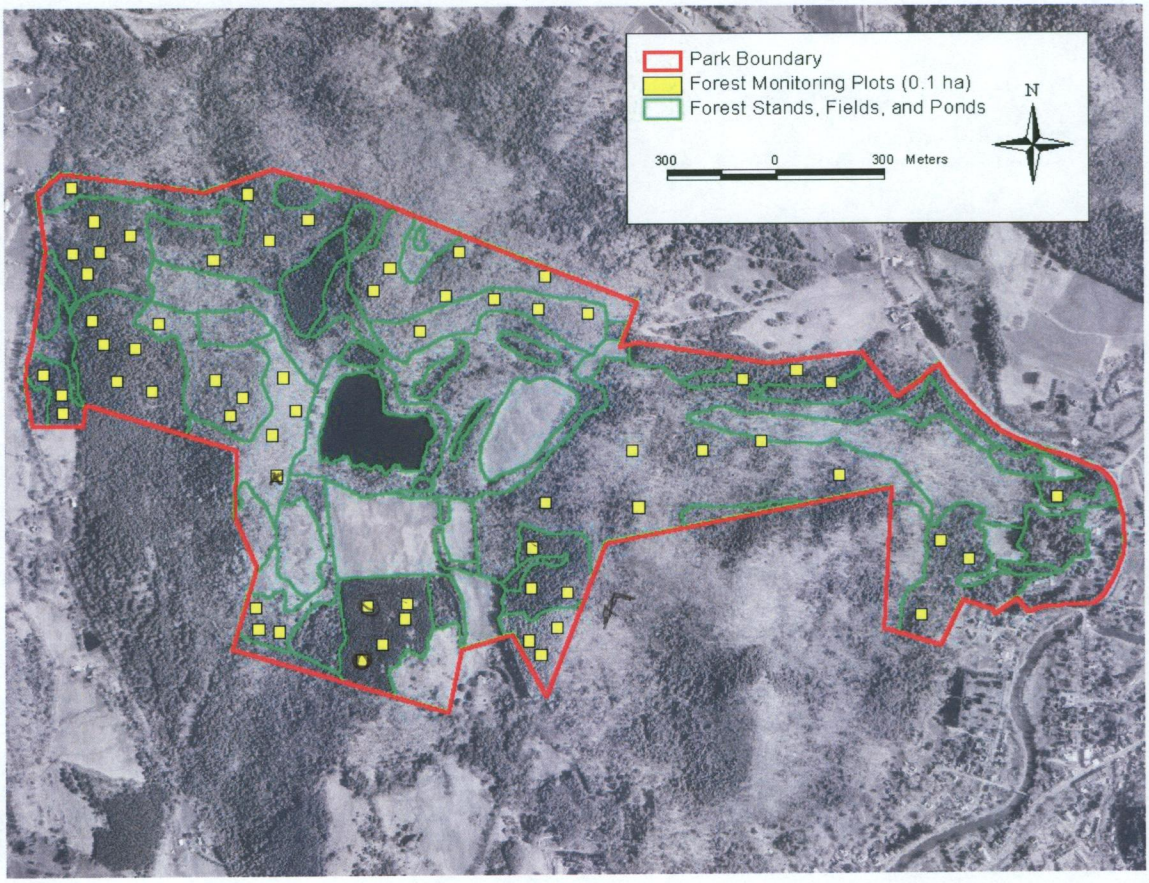


Figure 2. Location of permanent monitoring plots. The number of plots per reference stand is proportionate to the size of the stand. Plot distribution is based on a stratified random design. Plot sizes are shown to scale.

Each permanent plot consists of several nested square plots, line transects, and belt transects. Plot design and the corresponding attributes sampled are shown in Figure 3. Nested square plots are 0.1 ha, 0.05 ha, 0.02 ha, and 1 m^2 in size. There are thirteen m^2 quadrats used for estimating percent cover of all substrates (mineral soil, fine litter, rock, and coarse woody debris), understory plants by species (vascular and non-vascular plants), lichens, and above-ground fungal fruiting bodies. Canopy closure is measured at the center point of each quadrat using a spherical densitometer; litter layer depth is also measured at these points. Beginning in 2004, leaf area index will be measured using a Licor 2000 LAI meter.

In the 0.05 ha. plot, all live and dead trees > 5 cm dbh and > 1 m tall are permanently tagged at 1.37 m height, measured, and recorded by species, diameter, height, and decay class (snags only). Tree heights and crown depth on each tagged tree are measured using an Impulse 200 laser range finder. Assessments of tree health include coding of crown and bole condition, presence of disease and disturbance indicators, and presence of natural excavations and cavities. Additional forest

health indicators assessed include crown dieback, crown density, and foliage transparency, which are estimated by percentage class for dominant canopy trees. The 0.1 ha plot size is used to record the same information described above for trees over 50 cm dbh and snags over 1 m tall with upper diameters >10 cm. The cross sectional area of canopy gaps within the 0.1 ha plots is surveyed using an integrated GPS/laser range finder/digital electronic compass surveying system. Density and size class of tip-up mounds are measured within this plot size. The 0.02 ha. plot is used for tallying saplings (by species) that are > 1 m tall but < 5 cm dbh. Evidence of deer browse is also recorded by stem. Coarse woody debris (downed logs ≥10 cm diameter at intercept) volume by decay class (1-5) is estimated using a line intercept method. Tree seedlings (regeneration < 1 m height) are sampled by species within two belt transects that are each 1 m wide and 31.62 m long.

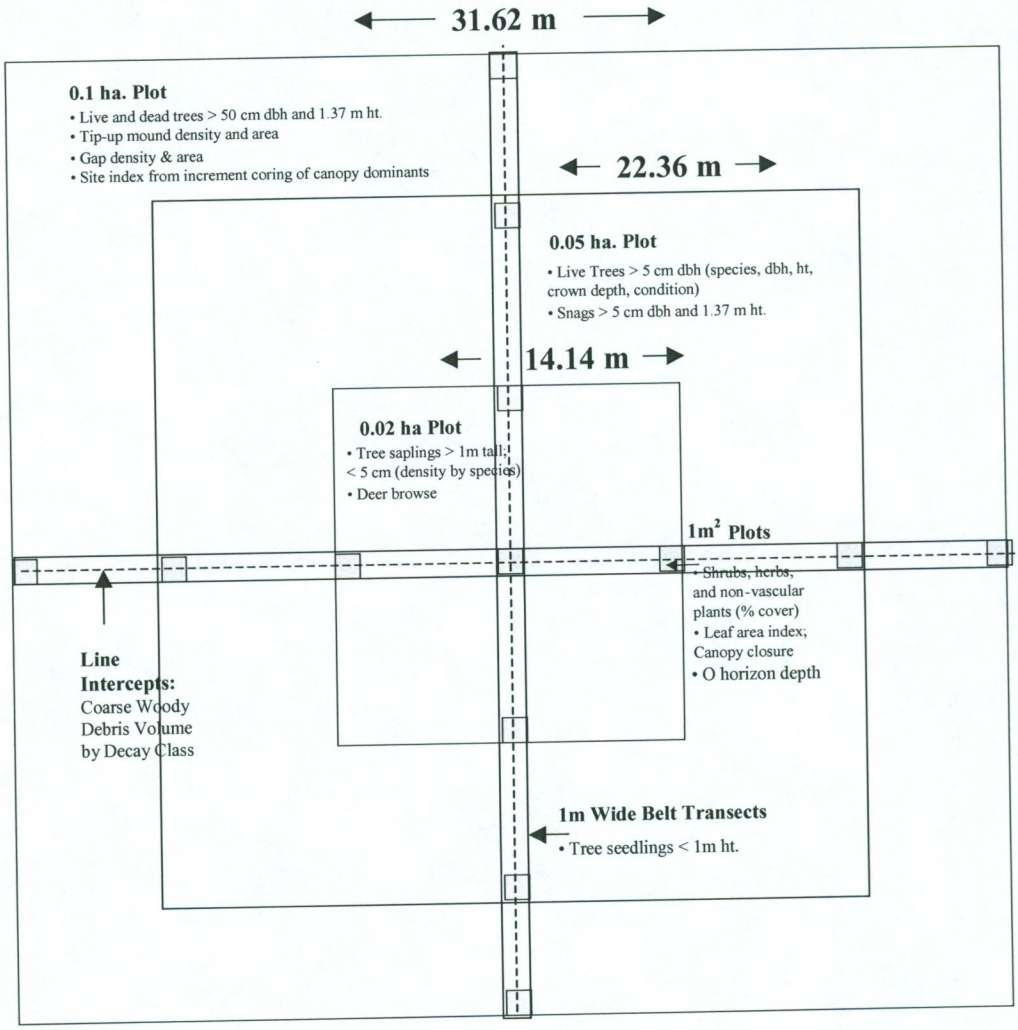


Figure 3. Design and parameters sampled in permanent plots. There are 62 of these plot systems distributed throughout the MBR National Historical Park.

The center point of each plot unit is mapped to within 1 - 30 cm horizontal precision using the GPS. Plot unit center points and the position of understory quadrats and line transects are permanently monumented. Two dominant canopy trees are cored at breast height to allow

subsequent laboratory determination of tree age and site index. Data are collected on slope, aspect, topographic position, and shape of topographic cross section.

Data analysis

The monitoring program relies on a suite of metrics generated from plot data. These metrics were selected as key indicators of forest structure, composition, and function, as well as for their usefulness in generating silvicultural prescriptions as per MBR's stewardship program. Each metric can be used explicitly to tract changes over time because they are linked directly to processes of stand development, health, and productivity, and because they respond to perturbations, such as stress or disturbance.

To generate basic forest inventory metrics, plot data were entered into the Northeast Decision Model (NED) (Simpson et al. 1996). Stand comparison statistics in Tables 1 and 2 are the output of NED calculations. Exceptions include stand age, which were based on laboratory analysis of increment cores, and natural community typing. The later was determined on a plot by plot basis through GIS analysis using natural community data provided by Lautzenheizer (2002) (Figure 4). Coarse woody debris volumes were calculated following Warren and Olsen (1964) as modified by Shivers and Borders (1996). I calculated mortality percentages by basal area and stem density for each stand. On-going analysis is evaluating mortality across multiple diameter classes. The objective is to identify the predominant mortality processes (e.g. density dependent competition vs. density independent exogenous factors, such as pathogens and natural disturbances) now operating across the Park's diversity of forests.

A number of methods were used to analyze forest compositional development. First, I programmed an MS Excel spreadsheet to sort overstory data by species and diameter class. The later followed USDA Forest Service timber-based diameter classes specific to northeastern U.S. conifers or hardwoods. These classes were used to facilitate conventional timber management planning. Diameter classes were as follows: sub-pole = 5 to 12.7 cm; pole = 12.7 to 27.7 cm (conifers) or 12.7 – 22.6 cm (hardwoods); small sawlogs = 27.7 to 37 cm (conifers) or 22.6 to 37 cm (hardwoods); and large sawlogs = 37 to 50 cm diameter at breast height (dbh). I also added classes (not included in the USDA Forest Service system) for seedlings (trees < 1 m height), saplings (trees > 1m height, < 5 cm dbh), and very large sawlogs (trees > 50 cm dbh). This made full use of all plot data and better represented the full spectrum of tree demography or age/size-based cohorts. I then calculated density by species within diameter classes as well as the proportion of total density represented by individual species. The proportions were graphed for each stand to provide a visual depiction of stand-specific tree demography, including responses to silvicultural management.

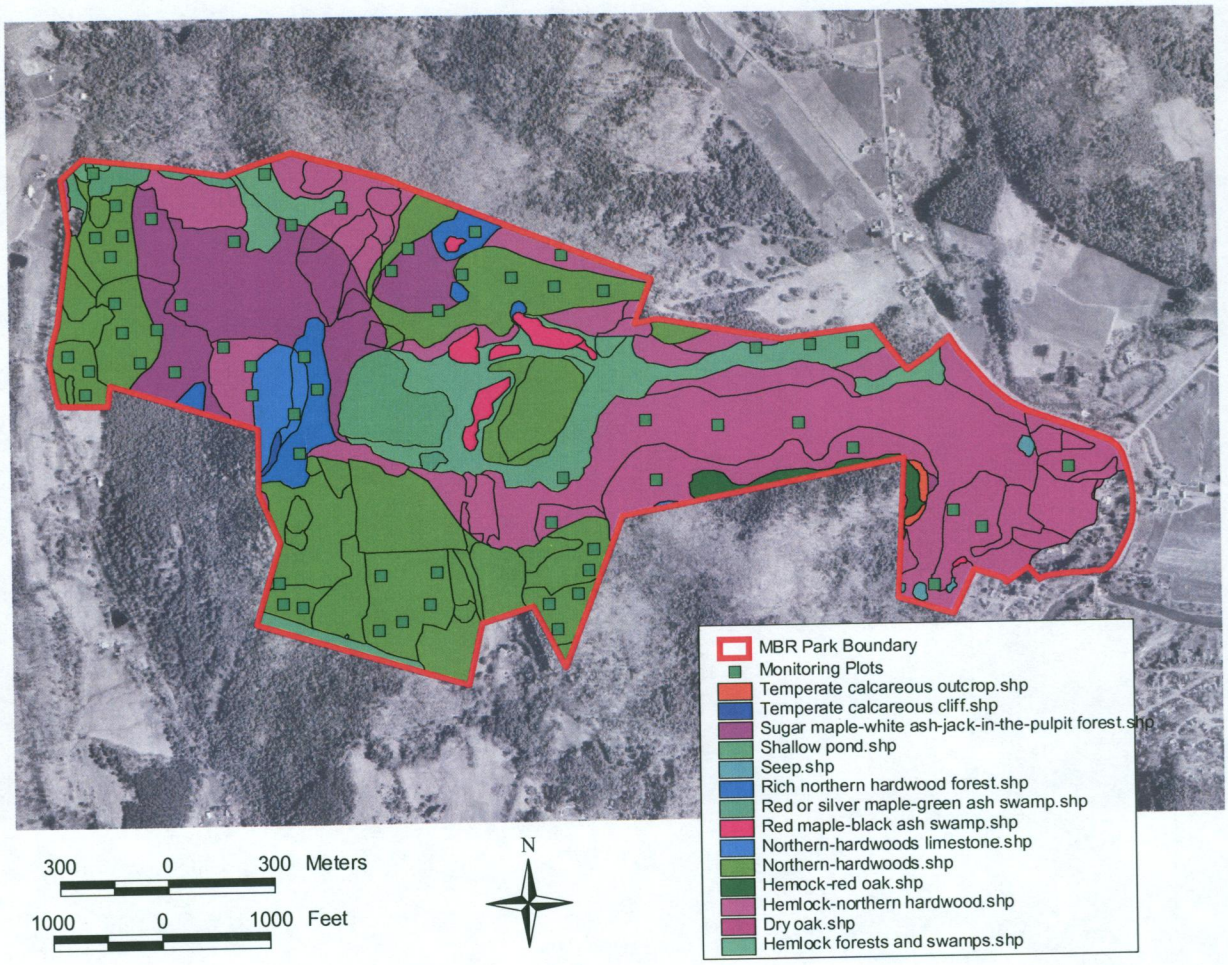


Figure 4. Permanent plot locations by natural community type. Natural community spatial data were provided courtesy of Tom Lautzenheizer, University of Vermont. Segregating plots by natural community, rather than current cover type or reference stand, provided a method for analyzing recolonization and successional trends. Tree demography and recruitment were analyzed relative to successional trajectories indicating development toward or away from a given natural community (or future potential vegetation).

To quantify the observed differences in species composition and relative abundance among cohorts, I calculated the Simpson's Dominance Index for each diameter class by plot. I aggregated plot-level dominance index values to the stand level and generated mean values and estimators of variance (standard deviation and standard error). The dominance index assesses the relative predominance of one or more species, with a value = 1 representing complete dominance by a single species and a lower value representing a more even distribution of individuals among multiple species. The index is especially useful for monitoring compositional changes in plantations initially dominated by a single tree species.

A second method used to analyze compositional and structural development employed linear regression analysis of diameter distributions. Density data were pooled for each plot and aggregated to the stand level. I used linear regression analysis to test for statistically significant negative exponential diameter distributions indicative (in the absence of abundant suppression) of stands developing uneven-aged structure. Alternate curves (e.g. exponential, logarithmic, linear, polynomial, etc.) were fitted using transformations of the independent variable. Based on the statistical strength of alternate curves, I determined if distributions were approaching a "balanced" negative exponential form versus a uni-modal or bi-modal form indicative of even or two-aged structure.

A final method used to assess compositional development focused on tree reproduction, quantified as the density of seedlings < 1 m height. This analysis determined whether trees in the overstory are reproducing and re-establishing in the understory. Conversely, tree regeneration might consist more significantly of species not found in the overstory that are colonizing the site. Regeneration data were segregated by overstory species or colonizing species for each plot. In semi-natural hardwood and hardwood-hemlock stands, colonizing vegetation was defined as non-native species, white or red pine, or early-successional species, such as cherries and poplars, not currently present in the overstory. In pure hemlock groves, any species other than hemlock was considered to be a colonizer. Plot data were sorted and aggregated by natural community type, plantation vs. semi-natural, and silvicultural management. Aggregation in this case was not based on reference stands, resulting in larger sample sizes and greater statistical power. Seedling densities were converted to proportions to normalize the overstory/colonizing regeneration ratios across all plots. *T*-tests assuming unequal variance were used to test for statistically significance differences in regeneration densities among the aggregate plot groupings.

Analysis of vertical structure (e.g. the vertical distribution of foliage and canopy layering) included the generation of several metrics, including dominant canopy height, the number of canopy layers, and foliage height diversity index. I created a program in MS Excel that calculates the vertical area occupied by individual tree crowns. Individual crown occupancies within increments of 1 m along a vertical gradient were then pooled for each plot, with individual tree contributions weighted by their respective basal area. A proportion was calculated for each strata representing its share of the stand's total foliage. These were aggregated to the stand level, allowing variance to be estimated. The vertical distribution of foliage was graphed for each stand, allowing determination of canopy height and layering. A foliage height diversity index was calculated from the pooled data based on the formula for the Shannon-Wiener Diversity Index. The index yields an estimate of both the diversity of canopy strata occupied by tree crowns and the evenness with which foliage is distributed among these. I used *T*- tests that assumed unequal variance to test for statistically significant differences in foliage height index among stand types.

Another important indicator of stand development, response to management and visitor impacts, and forest ecosystem health is the abundance and diversity of understory plants. To evaluate this indicator I sorted quadrat data for each plot by species. The mean percent cover for woody shrubs, herbaceous plants (including herbs, ferns and allies, grasses, and sedges), and bryophytes was calculated by averaging quadrat data (N=13 per plot). Percent cover data were then transformed into proportions of total cover on an individual species basis. Using these proportions, I calculated the Shannon-Wiener Diversity Index for each plot. Species richness also was calculated for each plot. Plot values for mean percent cover, diversity index, and species richness were aggregated to

the reference stand level. The fist two variables thus represent mean values throughout each reference stand, whereas the later represents mean richness at a scale of 0.1 ha; minimum and maximum species richness values were also calculated relative to this spatial scale. I compared understory plant variables for stand groupings using *T*-tests assuming unequal variance. In one instance, a *T*-test assuming equal variance was used, but a test of homogeneity of variance confirmed the equal variance assumption.

RESULTS

Stand inventory metrics

General stand inventory analysis results are presented in Tables 1 and 2. Theses results describe current and potential vegetation types (natural communities) where monitoring plots are located. They also provide basic metrics on stand structure and composition.

Current forest condition in MBR is highly diverse, with the mosaic of stands providing a number of different canopy architectures, ranging from single to multi-layered. Dominant canopy height varies widely, but is highest in old plantations. For instance, a European larch stand, reference stand #1, represents the Park's second highest canopy, due to stand density and the growth form and rates exhibited by that species. The Park's tallest primary canopy and tallest individual second growth trees are found in the 1880 white pine plantation (reference stand #45) at the base of Mt. Tom.

Other indicators suggest that forest structure varies widely throughout the Park, providing a diversity of wildlife habitats, carbon sequestration, and other ecological functions. For instance, basal areas in reference stands range from 27 to 62 m^3/ha; highest basal areas are reached in the Park's oldest coniferous plantations. Relative density (a metric that integrates basal area with stem density) also varies widely, suggesting a diversity of stocking densities and overstory growth rates. The Park's forests are fully stocked, with stocking levels near, above, or well above the B line in all cases. This represents a significant opportunity for continued forest stewardship.

The diversity in stocking densities also represents a diversity of wildlife habitats, such as hiding and resting cover versus foraging habitats, that are associated with differences in stand density and composition (DeGraaff and Yamasaki 2001). The juxtaposition of diverse patches over relatively small spatial scales represents a high quality habitat configuration for many wildlife species, especially generalists and those requiring multiple habitat types. This pattern may reduce habitat quality for some species, however, such as those associated with the interiors of specific patch types.

The metrics presented in Tables 1 and 2 will provide an efficient and ecologically meaningful system for monitoring changes in these forest characteristics and functions over time.

Table 1. General descriptive informative for reference stands.

Stand ID	Establishment Year of Dominant Cohort	Stand Type	Current USDA F. Serv. Cover Type	Natural Communities (Potential Veg.) Within Plots	Hard Mast	Fruit & Nut Trees	Dom. Canopy Height (m)	Canopy Structure
Stand 1	1887	Plantation	European larch	Northern-hardwoods	present	0%	38	Multi-Layered
Stand 2	1911	Plantation	Eastern white pine	Northern-hardwoods, Hemlock-northern hardwood	present	0%	37	Two-Layered
Stand 4	1952	Plantation	Red pine	Northern-hardwoods	present	0%	25	Single-Layered
Stand 8	1940	Semi-Natural	Mixed white pine-hardwoods	Northern-hardwoods	present	0%	28	Single to Two-Layered
Stand 13	1950	Plantation	Norway spruce	Northern-hardwoods	present	1%	26	Single-Layered
Stand 17	1917	Plantation	Red pine	Northern-hardwoods	present	0%	35	Two-Layered
Stand 18	1905	Plantation	Eastern white pine	Northern-hardwoods, Sugar maple-white ash-jack-in-the-pulpit forest	present	0%	37	Two-Layered
Stand 21	1890	Semi-Natural	Hemlock-hardwoods	Sugar maple-white ash-jack-in-the-pulpit forest, Hemlock-northern hardwood, Hemlock forests and swamps, Red or silver maple-green ash swamp	present	0%	32	Two to Multi-Layered
Stand 24	1890	Semi-Natural	Maple	Northern-hardwoods, Hemlock-northern hardwood, Sugar maple-white ash-jack-in-the-pulpit forest	present	0%	28	Multi-Layered
Stand 30	1900	Semi-Natural	Maple	Rich northern hardwood forest, Northern-hardwoods limestone	present	0%	29	Multi-Layered
Stand 31	1890	Semi-Natural	Spruce-northern hardwoods	Northern-hardwoods limestone, Hemlock-northern hardwood, Sugar maple-white ash-jack-in-the-pulpit forest,	present	0%	32	Two to Multi-Layered
Stand 33	1890	Semi-Natural	Oak-northern hardwoods	Northern-hardwoods, Sugar maple-white ash-jack-in-the-pulpit forest	present	1%	28	Two to Multi-Layered
Stand 38	1890	Semi-Natural	Hemlock	Hemlock forests and swamps	present	0%	30	Two to Multi-Layered
Stand 39	1910	Semi-Natural	Hemlock-hardwoods	Hemlock-northern hardwood, Hemlock forests and swamps	present	2%	27	Multi-Layered
Stand 42	1882	Plantation	Norway spruce	Hemlock-northern hardwood	present	0%	44	Multi-Layered
Stand 45	1880	Plantation	Eastern white pine	Hemlock-northern hardwood	present	0%	37	Two-Layered

Table 2. Forest inventory metrics for reference stands, including NED output.

Refer. Stand ID	q factor	Total Basal Area (m^2/ha)	Live Basal Area (m^2/ha)	Merch. Dbh (cm)	Avg. dbh (cm)	Quad. Dbh (cm)	Relative density	Trees / ha	Live Trees / ha	Dead Trees/ ha
Stand 1	1.09	54	50.8	34.65	21.55	24.85	67.4	1153.29	1046.62	106.67
Stand 2	1.04	51.3	50.1	49.83	23.06	29.92	98.3	746.64	713.3	33.34
Stand 4	1.06	53.7	48.2	47.73	25.18	28.04	119.1	823.97	779.97	44
Stand 8	1.07	59	55.9	61.9	21.08	27.52	121.8	1079.96	939.96	140
Stand 13	1.03	54.9	46.2	35.36	31.28	32.04	71.9	593.31	573.31	20
Stand 17	1.05	40.8	39.8	37.33	14.71	19.73	96.8	1327.95	1299.95	28
Stand 18	1.08	55	52.6	53.19	16.85	24.9	109.3	1183.95	1079.96	103.99
Stand 21	1.14	37.8	34.2	36.65	20.04	23.86	95.4	863.97	763.97	100
Stand 24	1.07	32.6	32.3	39.21	21.88	26.19	98.4	627.97	599.98	27.99
Stand 30	1.12	30.5	26.8	38.15	20.34	24.37	85.6	649.97	574.98	74.99
Stand 31	1.17	35.1	33.5	33.61	15.95	19.01	106	1309.95	1179.95	130
Stand 33	1.11	35.7	33.6	42.25	21.11	26.15	110.9	664.97	624.97	40
Stand 38	1.05	53.1	50.7	47.17	27.77	32.63	120.7	646.64	606.64	40
Stand 39	1.12	38.9	36.9	41.63	21.21	25.66	104.2	806.63	713.3	93.33
Stand 42	1.01	67.9	66.2	58.83	32.92	41.06	102.6	519.98	499.98	20
Stand 45	1.04	64.3	58.7	67.85	30.38	38.93	114.1	606.64	493.31	113.33

Size class distributions and species dominance

The results clearly show that stand development pathways and rates differ throughout the Park as a function of management history. There are distinct differences in community diversification within size classes, as indicated by the dominance index values presented in Table 3 for individual reference stands. Rates of successional development, with faster rates indicated by lower dominance values, vary between plantations and semi-natural forests. In un-thinned plantations, planted species continue to dominate most size classes, with little regeneration of other species, including native hardwood species endemic to most of the Park's plantation sites (Figure 5, top). As a result, dominance index values remain high, often close to 1 (or complete dominance) across both large and small size classes (Figure 6, top).

Table 3. Simpson's dominance index by timber size class for selected reference stands. An index value of 1.00 means that only one species occupies a size class, implying complete dominance of that size class.

	Seedlings		Saplings		Sub Pole-sized		Pole-sized		Small Sawlogs		Large Sawlogs		Very Large Sawlogs	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Stand 2	0.42	0.24	0.23	0.14	0.57	0.33	0.44	0.25	0.62	0.36	1.00	0.58	0.00	0.00
Stand 4	0.72	0.32	1.00	1.00	0.80	0.46	0.83	0.37	0.94	0.42	1.00	1.00	1.00	0.71
Stand 8	0.68	0.39	1.00	0.71	0.75	0.43	0.72	0.41	0.69	0.40	1.00	0.58	0.69	0.40
Stand 13	0.94	0.54	0.00	0.00	0.00	0.00	0.43	0.17	0.95	0.55	0.64	0.37	1.00	0.71
Stand 17	0.46	0.20	0.36	0.16	0.27	0.12	0.79	0.46	0.90	0.40	0.95	0.43	0.00	0.00
Stand 18	0.95	0.43	0.29	0.13	0.37	0.16	0.70	0.31	0.81	0.36	1.00	0.50	1.00	0.45
Stand 21	0.49	0.22	0.65	0.33	0.43	0.19	0.44	0.20	0.57	0.26	0.70	0.31	0.92	0.46
Stand 24	0.66	0.30	0.53	0.30	0.71	0.32	0.81	0.36	0.72	0.32	0.88	0.39	0.75	0.33
Stand 30	0.91	0.46	0.75	0.43	0.74	0.37	0.83	0.41	0.68	0.34	0.80	0.40	0.70	0.41
Stand 31	0.74	0.37	0.88	0.44	0.42	0.21	0.39	0.19	0.72	0.36	0.78	0.39	0.85	0.49
Stand 33	0.71	0.35	0.73	0.37	0.50	0.25	0.55	0.28	0.48	0.24	0.91	0.45	0.67	0.34

Plantations that have been thinned show successional development that is markedly different from un-thinned plantations. Thinning has increased light availability, allowing other species to recolonize the site. As a result, species dominant in the overstory are being almost entirely replaced by recruitment of native hardwoods into the understory and mid-canopies (Figure 5, bottom). The effect of this development to date has been reduced dominance and increased community diversity in seedling to sub-pole classes (Figure 6, bottom). Over time, as mortality in the overstory continues to open up growing space, native hardwoods will move into larger size classes, ultimately replacing overstory conifers. The results show that Simpson's dominance index, measured for discrete size classes, will be an efficient metric for monitoring this process of recovery.

There also are differences in successional rates among semi-natural stands based on the data. The Park's semi-natural stands appear to vary with respect to overstory self-perpetuation through conspecific recruitment versus community diversification through recruitment of additional mid- to late-successional species. Examination of size class plots (by species) consistently showed un-managed (i.e. little or no timber harvest) stands to have lower rates of diversification (Figure 7, top), and thus higher dominance values across most size classes (Figure 8, top). Stands which have had intermediate silvicultural treatments (i.e. thinning) and low intensity regeneration harvests (e.g. single-tree selection) appear to have greater diversification across multiple size

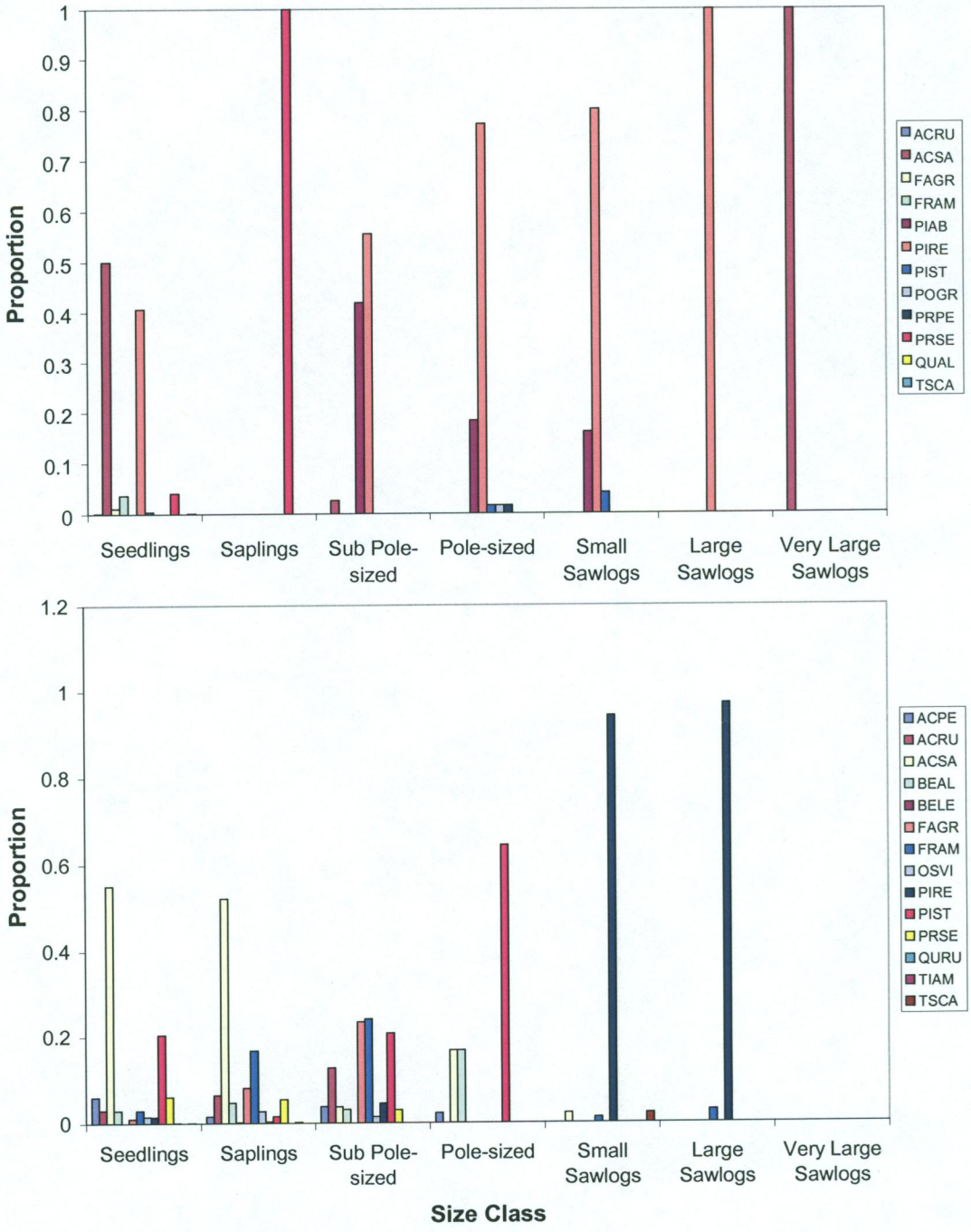


Figure 5. Timber size class distributions segregated by tree species code (first two letters of genus and species) in reference plantations. An un-thinned red pine plantation (reference stand #4) planted in 1953 (above) is compared with a thinned 1917 red pine plantation (reference stand #18) (below). Note the static dominance across most size classes of red pine (PIRE) in the un-thinned plantation. While the species is regenerating, no seedlings are surviving into the sapling stage, which is exclusively dominated by suppressed, transient black cherry (PRSE). Note the contrast with the thinned plantation, in which recruiting and mid-sized cohorts are now dominated by a diversity of native hardwood species, which are recolonizing the site, developing vertically, and ultimately replacing the overstory red pine. The "very large sawlogs" in the top figure are open-grown (or "wolf"), legacy sugar maple, now embedded within the younger plantation.

classes. As a result, dominance values are lower in the size classes that have diversified (Figure 8, bottom). Other factors, such as differences in seed source availability, site productivity, and dominant species composition may co-vary with management history. Thus while low intensity silviculture appears to have increased rates of successional development in semi-natural stands, this interpretation of the results carries a degree of uncertainty.

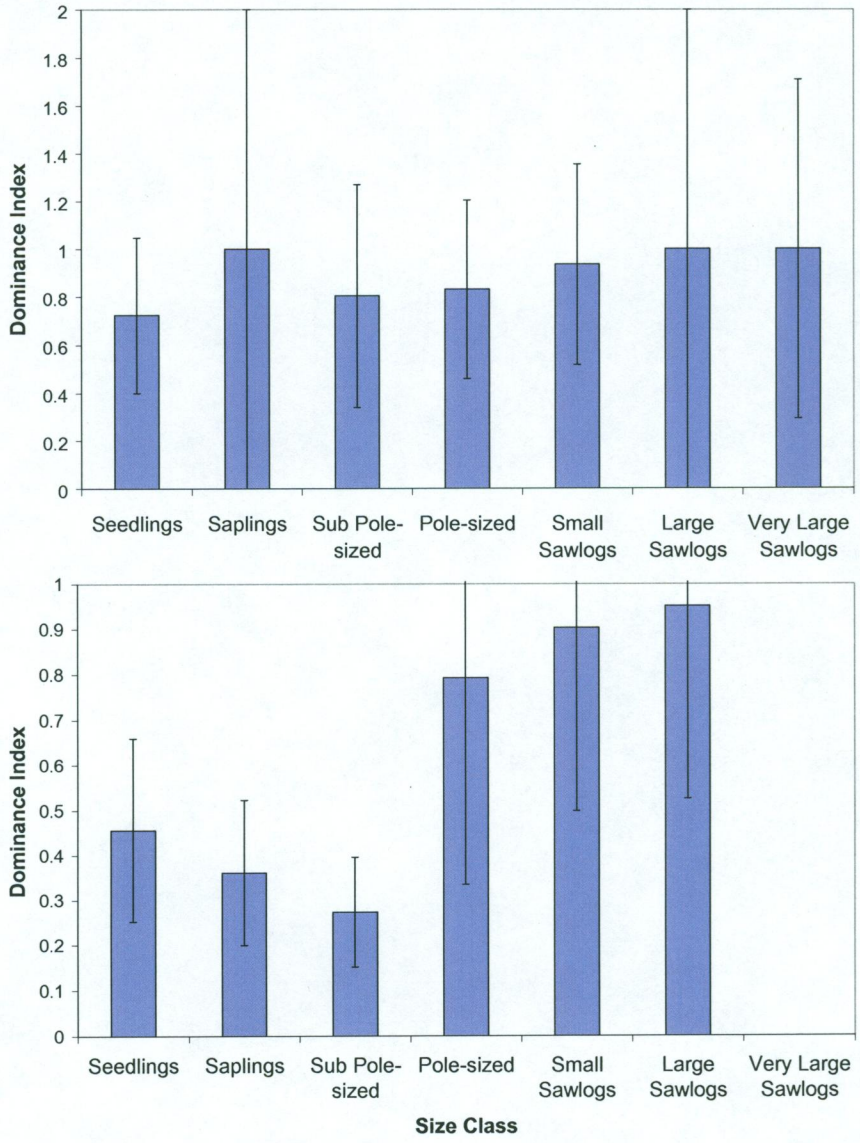


Figure 6. Simpson's Dominance Index for timber size classes in reference plantations. An un-thinned red pine plantation planted in 1953 (above) is compared with a thinned 1917 red pine plantation (below). In the thinned plantation, note the reduced single species dominance in the smaller size classes due to recruitment of site-endemic species, resulting in diversified species composition. Error bars show +/- one standard error of the mean.

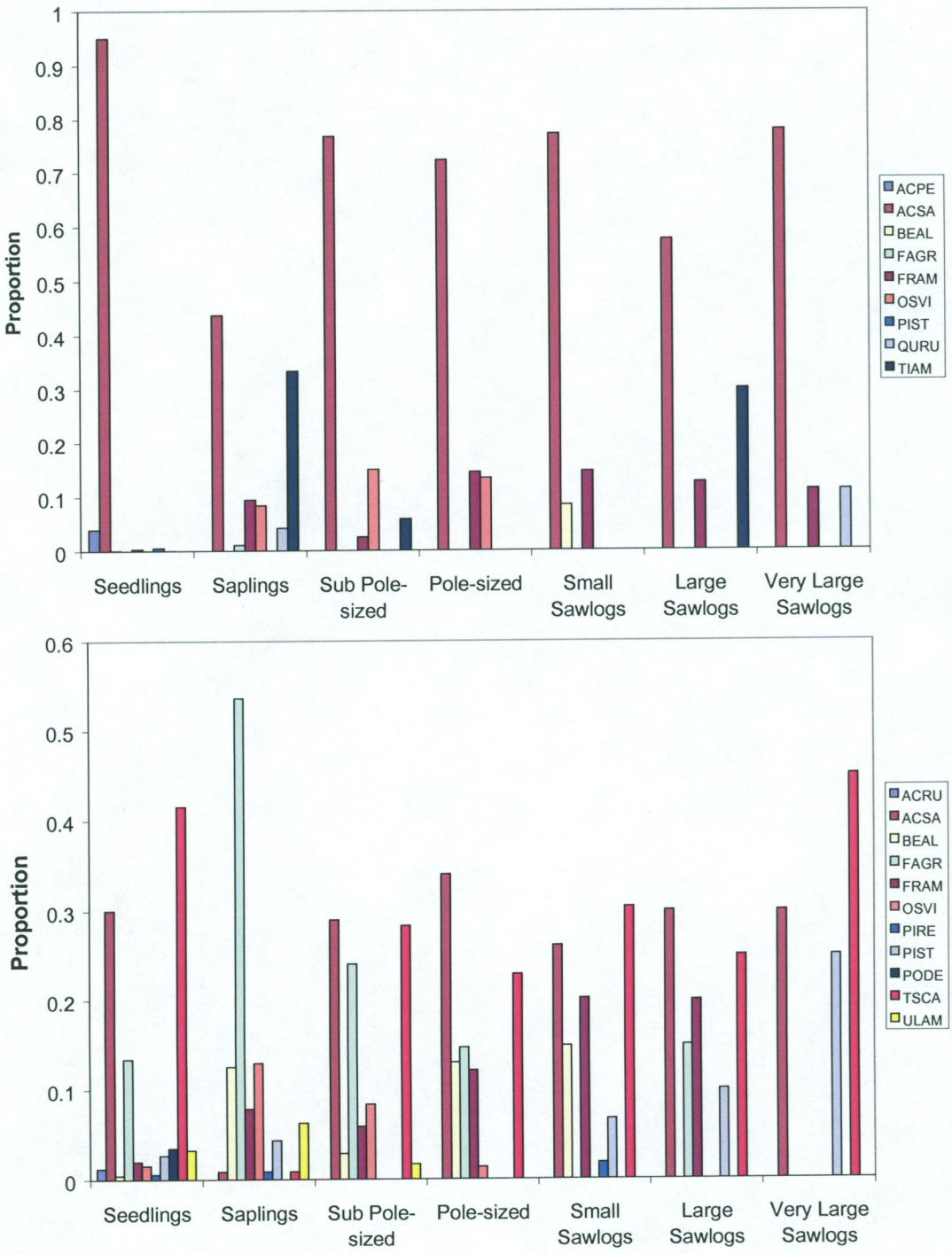


Figure 7. Timber size class distributions segregated by tree species code (first two letters of genus and species) in reference semi-natural stands. A rich northern hardwood stand that has not been silviculturally managed (reference stand #30) is shown above, and a northern hardwood-hemlock stand (reference stand #21) that has been silviculturally managed is shown below. Note the self-perpetuation of the dominant sugar maple (ACSA) above, versus the more diverse species composition below. These trends may reflect natural differences in successional dynamics and/or they may have been influenced by management differences.

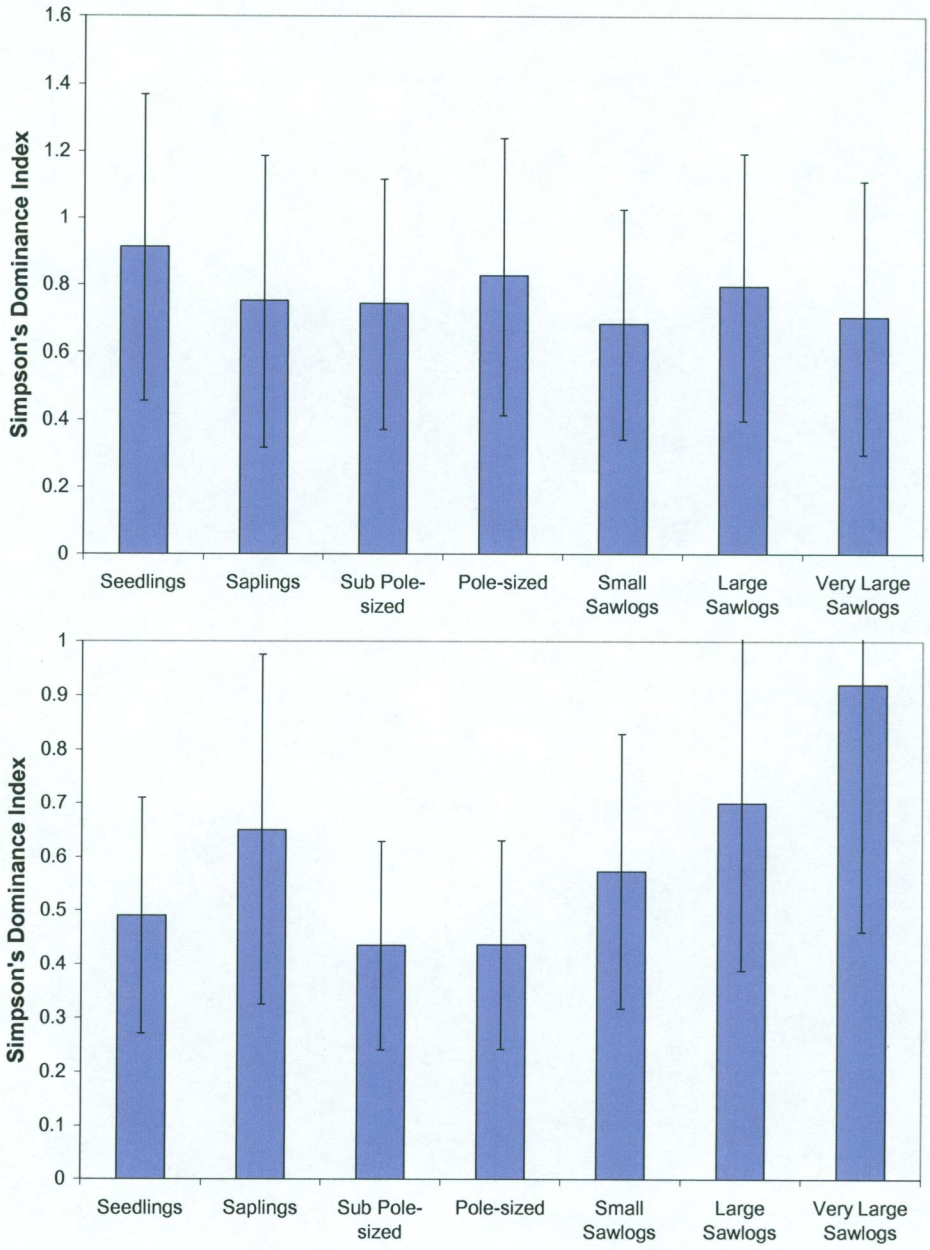


Figure 8. Simpson's Dominance Index for timber size classes in reference semi-natural stands. A rich northern hardwood stand that has not been silviculturally managed is shown above, and a northern hardwood-hemlock stand that has been silviculturally managed is shown below. Note the lower index values for seedling through pole-sized classes in the silviculturally managed stand (below). Error bars show +/- one standard error of the mean.

Regression analysis of size class distributions for semi-natural stands resulted in negative exponential relationships that were statistically significant ($\alpha = 0.05$). Negative exponential trend lines generally had tighter fits than other curves, explaining 50 to 90% of the variability in residuals (Figure 9). Some younger, more structurally simple stands, however, had uni- or bi-modal tendencies (Figure 9, lower left). In general, however, the regression results suggest that the Park's maturing semi-natural stands are developing or have developed uneven-sized class

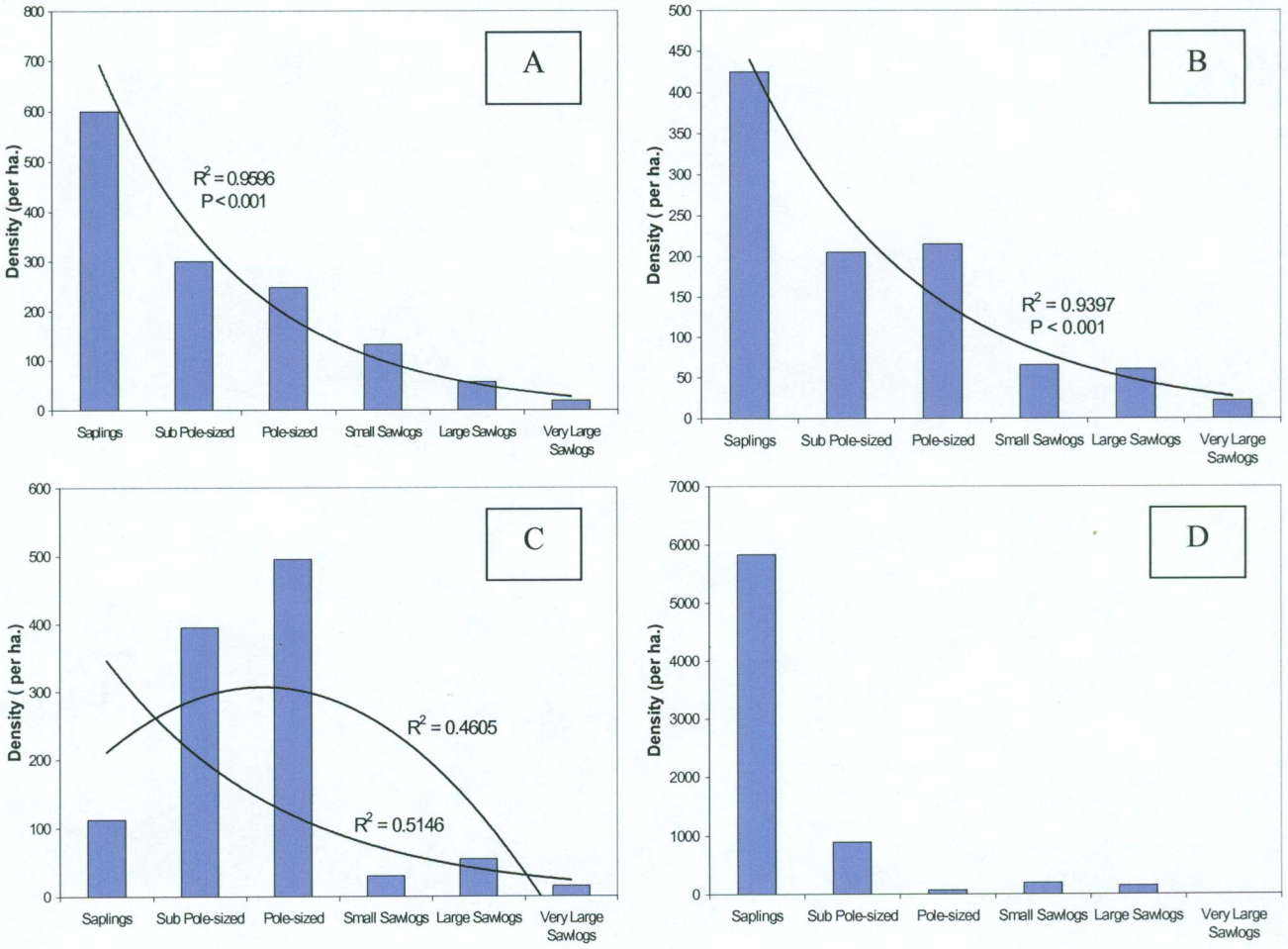


Figure 9. Size class distributions and regression curves for A) a silviculturally managed, semi-natural stand (reference stand #21); B) a highly productive though un-managed, semi-natural stand (reference stand #30); C) a lightly managed, lower productivity semi-natural stand (reference stand #31); and D) a thinned 1917 red pine plantation (reference stand #17). In each case, succession and/or management has moved stand structure toward an un-even size (and potentially age) class distribution. A possible exception, indicative of the Park's slower developing hardwood forests, is Example C, which has uni-modal, even-aged characteristics, despite a stronger regression fit to a negative exponential curve.

distributions characteristic of uneven-aged forests. Field data and increment coring confirmed that these distributions are not an artifact of suppression in small to mid-sized trees. Rather, they represent multiple age cohorts, although some degree of suppression is always present. This is another indication that semi-natural stands are developing the structural complexity associated with late-successional forests. Silvicultural management may have accelerated this process in some stands (Figure 9 upper left), although the Park's most productive, un-managed semi-natural stands show similar rates of structural development (Figure 9, upper right).

Thinned plantations also are developing uneven-aged diameter distributions, with very high q ratios (e.g. > 1.9, includes saplings < 5 cm dbh) as a result of prolific recruitment of hardwoods into the smallest size classes (Figure 9, lower right). Q ratios in plantations are shallow (1.1) to flat (1.0) when ratio calculations do not include the pulse of saplings and sub-pole sized trees established after thinning. To some degree, however, thinned plantations are developing characteristics indicative of

late-successional structure, albeit in this case an unusual mix of sometimes non-endemic conifers in one canopy layer and native hardwoods in the other canopy layers.

Tree recruitment dynamics and demography

Analysis of tree regeneration data resulted in significant differences between plot groupings. These differ by natural community type and management history (Table 4). In hardwood and mixed-wood forests as a whole, reproduction by overstory species is significantly ($P<0.0001$) more abundant than is colonizing reproduction by exotic species or species not currently represented in the stand (Figure 10, upper left). The only natural community type represented in semi-natural stands that does not show this trend is hemlock forests and swamps. In those patches, reproduction by hemlock is minimal, with the majority of regeneration consisting of non-overstory species. Non-overstory seedlings are more abundant in hemlock groves, but this relationship is only statistically significant at a 90% probability level (Figure 10, lower right).

Table 4. Tree regeneration data by seed source, plot, natural community, and stand management.

Plot	Natural Community (Potential Veg.)	Plantation	Thinned Plantation	Managed Hardwoods	Overstory Reproduction (Density per ha.)	Colonizing Reproduction (Density per ha.)	Notes
1	Rich Northern Hardwood Forest	No		No	207911.4	0	
2	Hemlock-northern hardwood	Yes	Yes		0	226582.2	
3	Hemlock-northern hardwood	Yes	Yes		0	53639.22	
4	Hemlock-northern hardwood	Yes	No		335442.9	18354.42	
5	Hemlock-northern hardwood	No		Yes	32911.38	0	
6	Hemlock forests and swamps	No		No	2689.873	25316.45	
7	Hemlock forests and swamps	No		No	632.9112	42879.73	
8	Hemlock forests and swamps	No		No	1424.05	5537.973	
9	Hemlock-northern hardwood	No		Yes	20569.61	0	
10	Hemlock-northern hardwood	No		Yes	41613.91	0	
11	Hemlock-northern hardwood	No		Yes	31962.02	0	
12	Hemlock forests and swamps	No		Yes	632.9112	30537.97	
13	Hemlock-northern hardwood	Yes	Yes		791.139	62025.3	
14	Northern-hardwoods	Yes	Yes		2531.645	23892.4	Anomalous due to legacy sugar maples
15	Northern-hardwoods	Yes	Yes		791.139	42721.51	
16	Northern-hardwoods	Yes	Yes		0	117405	
17	Northern-hardwoods	Yes	Yes		0	58227.83	
18	Northern-hardwoods	Yes	Yes		0	16930.37	
19	Northern-hardwoods	Yes	No		7278.479	349999.9	
20	Northern-hardwoods	Yes	No		2689.873	2056.961	
21	Northern-hardwoods	Yes	No		1740.506	300791	
22	Northern-hardwoods	Yes	No		1424.05	1424.05	
23	Northern-hardwoods	No		Yes	192246.8	632.9112	
24	Northern-hardwoods	No		No	33069.61	1107.595	
25	Northern-hardwoods	No		No	54746.82	632.9112	
26	Rich Northern Hardwood Forest	No		No	74208.84	0	
27	Rich Northern Hardwood Forest	No		No	108860.7	0	
28	Northern-hardwoods limestone	No		No	169145.5	316.4556	
29	Hemlock-northern hardwood	No		Yes	313132.8	316.4556	
30	Northern-hardwoods	No		Yes	94778.45	0	
31	Northern-hardwoods	No		Yes	64082.26	0	
32	Rich Northern Hardwood Forest	No		Yes	80063.27	158.2278	
33	Northern-hardwoods	No		Yes	270886	0	Anomalous due to legacy sugar maples
34	Northern-hardwoods	No		Yes	168829.1	0	

Table 4. (Continued)

Plot	Natural Community (Potential Veg.)	Plantation	Thinned Plantation	Managed Hardwoods	Overstory Reproduction (Density per ha.)	Colonizing Reproduction (Density per ha.)	Notes
35	Sugar maple-white ash-jack-in-the-pulpit forest	No		Yes	61392.39	316.4556	
36	Sugar maple-white ash-jack-in-the-pulpit forest	No		Yes	42721.51	86234.15	Anomalous due to proximity to Norway Spruce stand
37	Sugar maple-white ash-jack-in-the-pulpit forest	No		Yes	7436.707	4113.923	
38	Hemlock-northern hardwood	No		Yes	66455.68	158.2278	
39	Hemlock-northern hardwood	No		Yes	34018.98	0	
40	Sugar maple-white ash-jack-in-the-pulpit forest	No		Yes	21677.21	0	
41	Hemlock forests and swamps	No		Yes	32911.38	2215.189	
42	Sugar maple-white ash-jack-in-the-pulpit forest	No		Yes	13924.05	2689.873	
43	Hemlock-northern hardwood	No		Yes	46993.66	9018.985	
44	Hemlock-northern hardwood	No		Yes	178797.4	8227.846	
45	Northern-hardwoods limestone	No		Yes	117879.7	6170.884	
46	Northern-hardwoods	Yes	No		444936.6	16455.69	
47	Sugar maple-white ash-jack-in-the-pulpit forest	No		Yes	35284.8	178322.7	Anomalous due to proximity to white pine stand
48	Northern-hardwoods	Yes	No		299525.2	2689.873	
49	Sugar maple-white ash-jack-in-the-pulpit forest	Yes	No		466455.6	6962.023	
50	Northern-hardwoods	Yes	No		363449.3	17721.51	
51	Northern-hardwoods	Yes	No		302531.6	5379.745	
52	Northern-hardwoods	Yes	Yes		156803.7	12025.31	
53	Northern-hardwoods	Yes	Yes		62974.66	1582.278	
54	Northern-hardwoods	Yes	Yes		90031.62	474.6834	
55	Northern-hardwoods	Yes	No		33860.75	1424.05	
56	Northern-hardwoods	Yes	Yes		3481.012	46202.52	
57	Northern-hardwoods	Yes	Yes		0	42405.05	
58	Northern-hardwoods	Yes	Yes		0	10917.72	
59	Red or silver maple-green ash swamp	No		Yes	12816.45	0	
60	Northern-hardwoods	Yes	Yes		0	89556.93	
61	Sugar maple-white ash-jack-in-the-pulpit forest	Yes	Yes		19145.56	0	
62	Hemlock-northern hardwood	Yes	Yes		7911.39	24999.99	

Silvicultural management may have increased overstory reproduction rates, relative to colonizing species, based on the results (Figure 10, upper right). Overstory regeneration was significantly more abundant than colonizing seedlings in managed stands ($P<0.0001$). In un-managed hardwood and hardwood-hemlock stands, overstory reproduction was also greater than colonizing reproduction, but this relationship was not statistically significant ($P=0.11$). This fact explains the lack of a stronger statistical relationship when all semi-natural stands, managed and un-managed, are analyzed as one group (Figure 10, upper left).

Seedling recruitment in plantations showed similar dynamics, although weighted in the opposite direction (Figure 11). For plantations as a whole, species associated with natural communities may be recruiting slightly more abundantly than overstory conifers, but this relationship is not statistically significant ($P=0.23$). But when thinned plantations are compared with un-thinned

plantations, a much stronger relationship emerges. In thinned plantations colonizing species are recruiting far more abundantly than overstory species (Figure 11, lower left) (P=0.047). Un-thinned plantations, by contrast, have significantly (P=0.005) higher densities of seedlings reproduced by the overstory, with only small amounts of colonizing reproduction (Figure 11, lower right). Very dramatic exceptions to this can be found where legacy hardwood trees, either old-growth or open grown, are embedded within conifer plantations. Plot data showed that legacy trees are acting as seed sources for native hardwood species, resulting in prolific colonizing reproduction (see Table 4, stand # 4). It can be concluded than thinning in plantations redirects successional pathways toward natural community recovery. It also significantly increases successional rates, defined as accelerated understory re-initiation leading to vertical development and differentiation of the canopy.

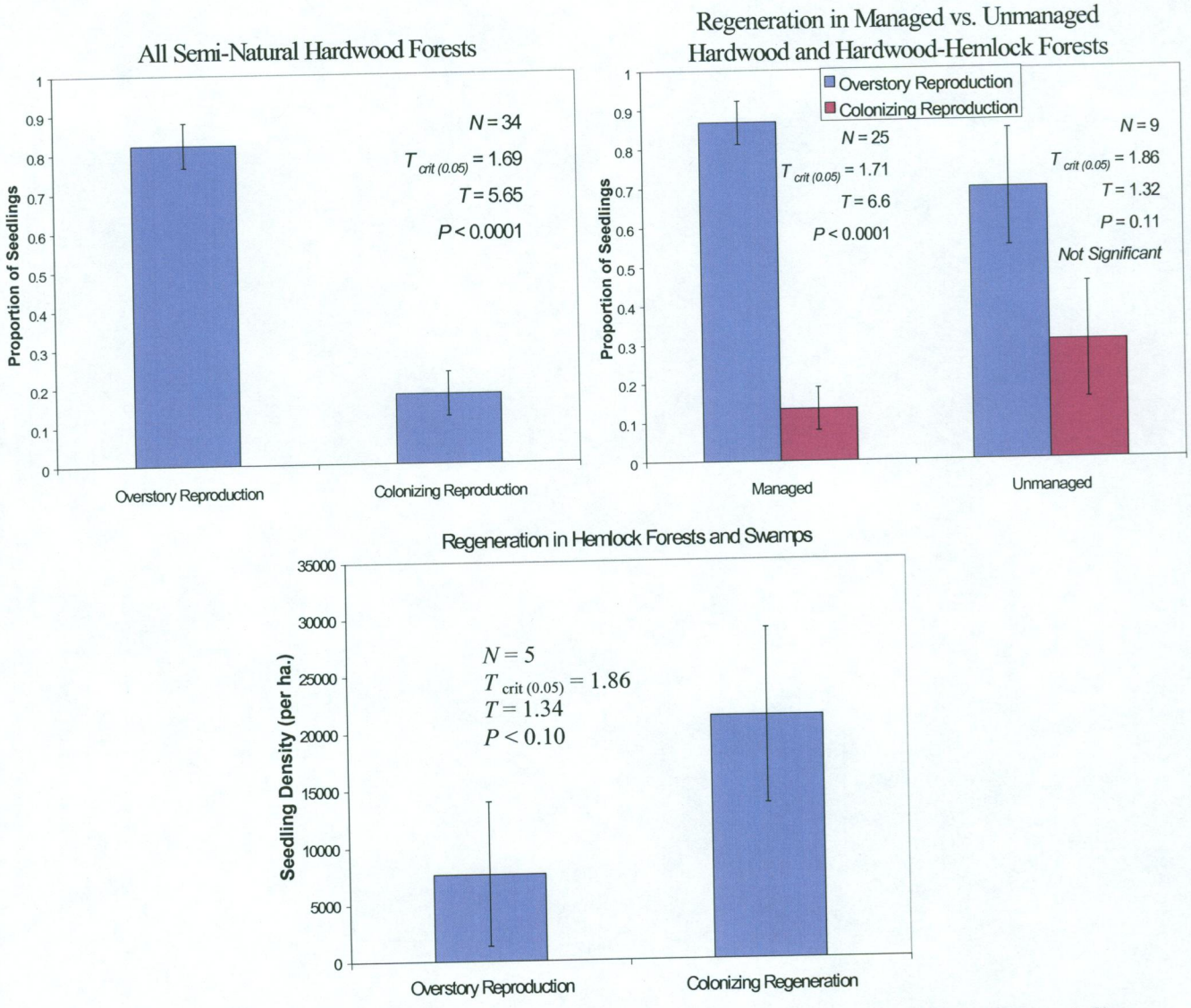


Figure 10. Tree regeneration ratios (overstory vs. colonizing reproduction) for all semi-natural stands (upper left), silviculturally managed vs. un-managed (upper right), and hemlock forests (bottom). Error bars show +/- one standard error of the mean.

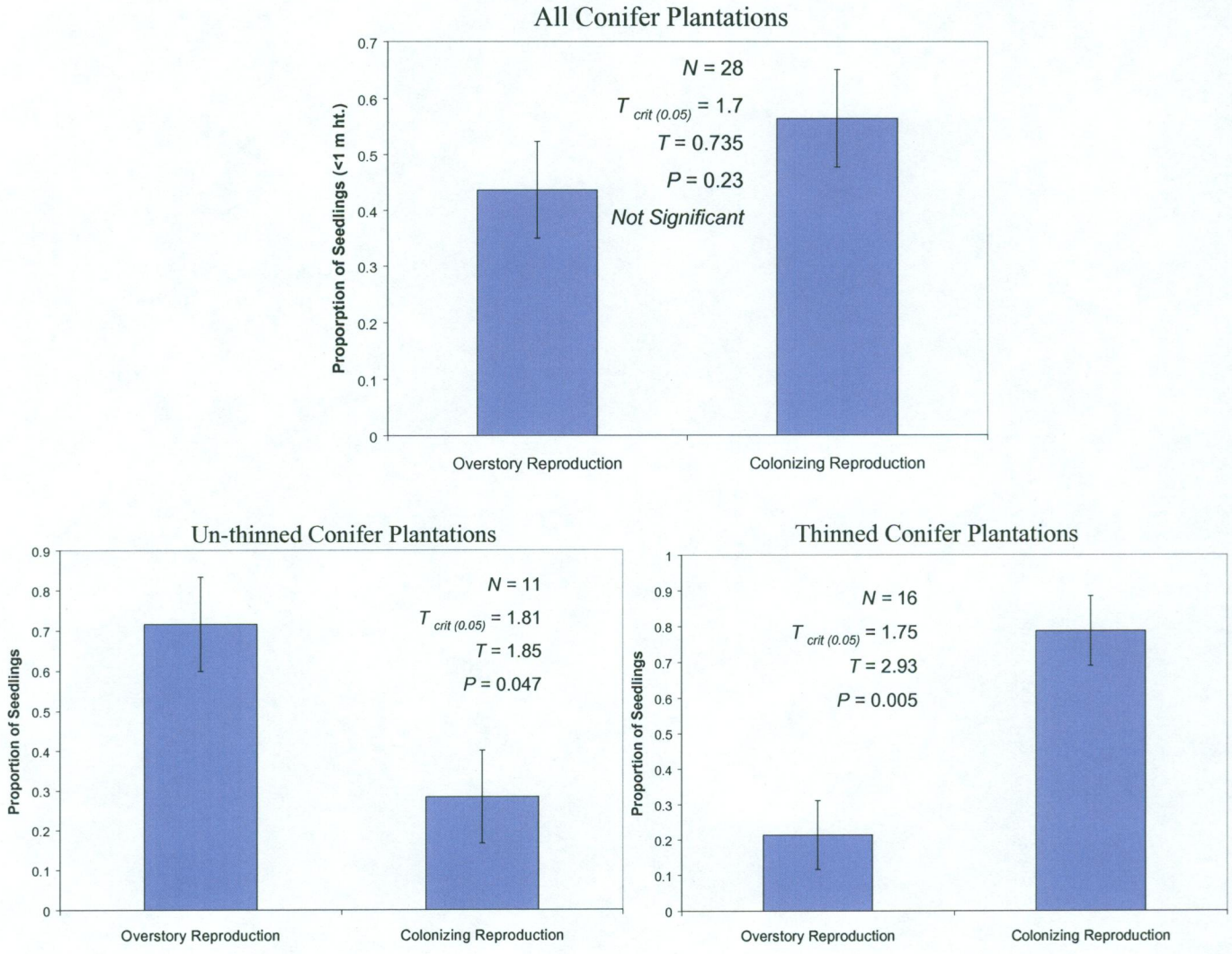


Figure 11. Tree regeneration ratios (overstory vs. colonizing reproduction) for all plantations (top), un-thinned plantations (bottom left), and thinned plantations (bottom right). Inverse relationships in the lower charts cancel one another in the upper chart. Error bars show +/- one standard error of the mean.

Mortality

Mortality data are presented in Table 5 and graphed in Figure 12. Tree mortality rates vary widely among the Park's forest stands. As a percentage of basal area, mortality rates are highest in reference stands 4, 13, and 30. This metric correlates with larger diameter trees, suggesting that those stands have experienced higher levels of mortality in overstory trees. There is likely to be intense competition and self-thinning in dense, un-thinned plantations (e.g. stands 4 and 13). This contrasts with density-independent mortality processes (e.g. wind throw and pathogens) operative in low density, mature hardwood stands, such as stand 30. Both would result in overstory tree mortality.

Mortality as a percentage of stem density is highest in a range of stand types, most of which have dense sapling-sized and mid-canopy layers. The data suggest, therefore, that Park stands in this structural condition will have elevated levels of competition and self-thinning from-below-the-canopy, resulting in mortality among sub-dominant and suppressed size classes.

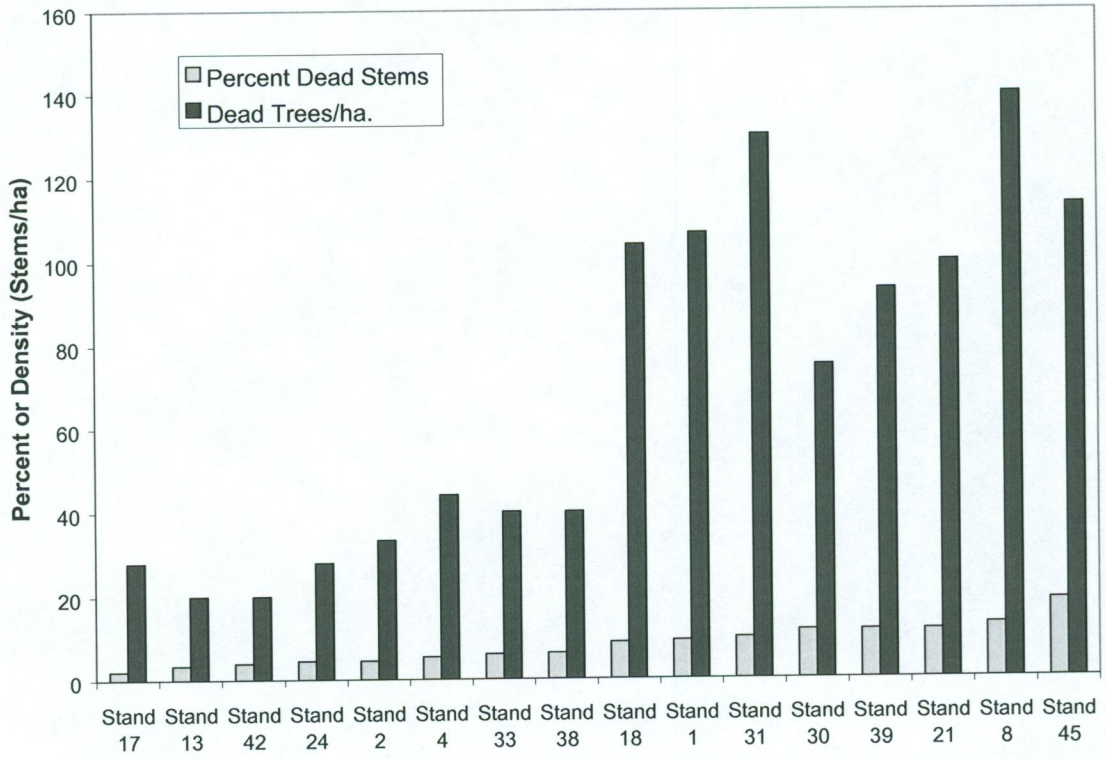


Figure 12. Reference stands ranked by dead tree densities and mortality as a percentage of total stems.

Table 5. Tree mortality data: densities and basal area.

	Percent Dead Stems	Dead Trees/ha.	Dead Tree Basal Area	Percent Dead Basal Area
Stand 1	9.25	107	3.20	5.93
Stand 2	4.47	33	1.20	2.34
Stand 4	5.34	44	5.50	10.24
Stand 8	12.96	140	3.10	5.25
Stand 13	3.37	20	8.70	15.85
Stand 17	2.11	28	1.00	2.45
Stand 18	8.78	104	2.40	4.36
Stand 21	11.57	100	3.60	9.52
Stand 24	4.46	28	0.30	0.92
Stand 30	11.54	75	3.70	12.13
Stand 31	9.92	130	1.60	4.56
Stand 33	6.02	40	2.10	5.88
Stand 38	6.19	40	2.40	4.52
Stand 39	11.57	93	2.00	5.14
Stand 42	3.85	20	1.70	2.50
Stand 45	18.68	113	5.60	8.71

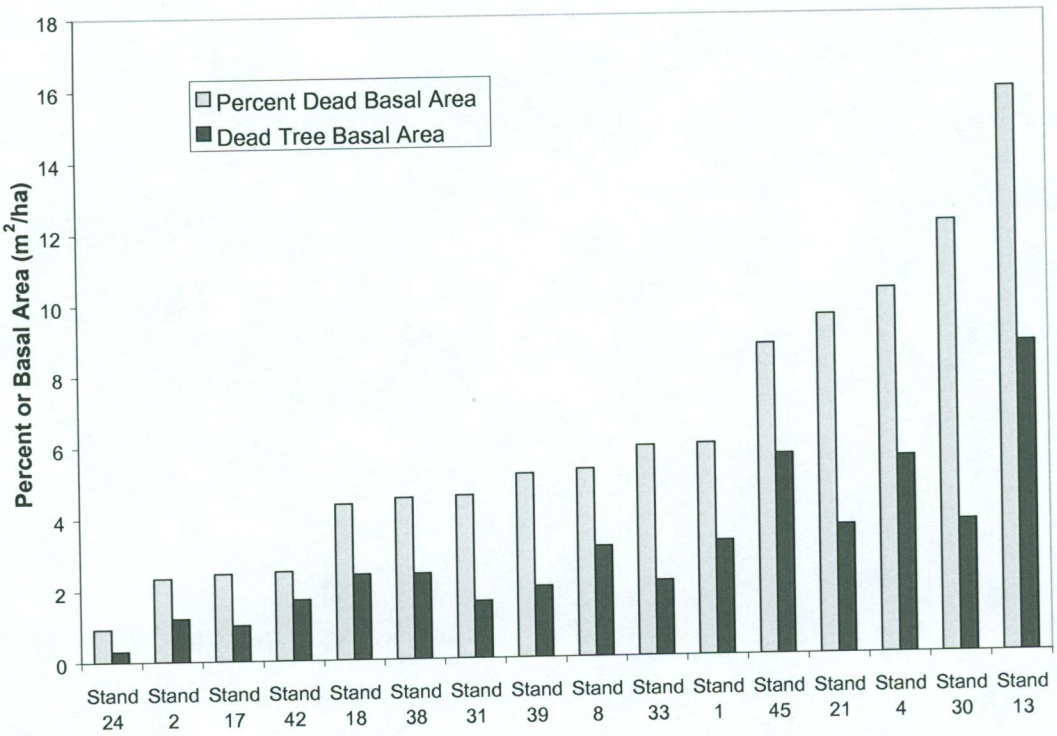


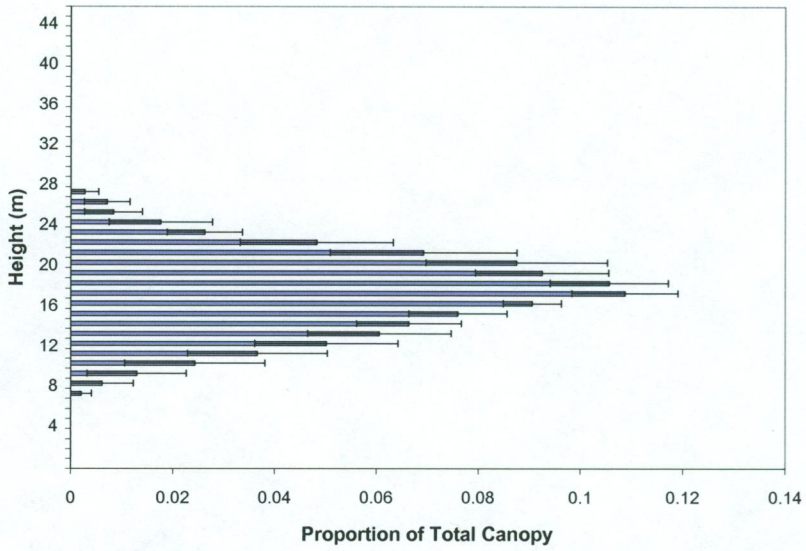
Figure 13. Reference stands ranked by dead tree basal area and mortality as a percentage of total basal area.

Vertical structure: foliage height distribution and diversity index

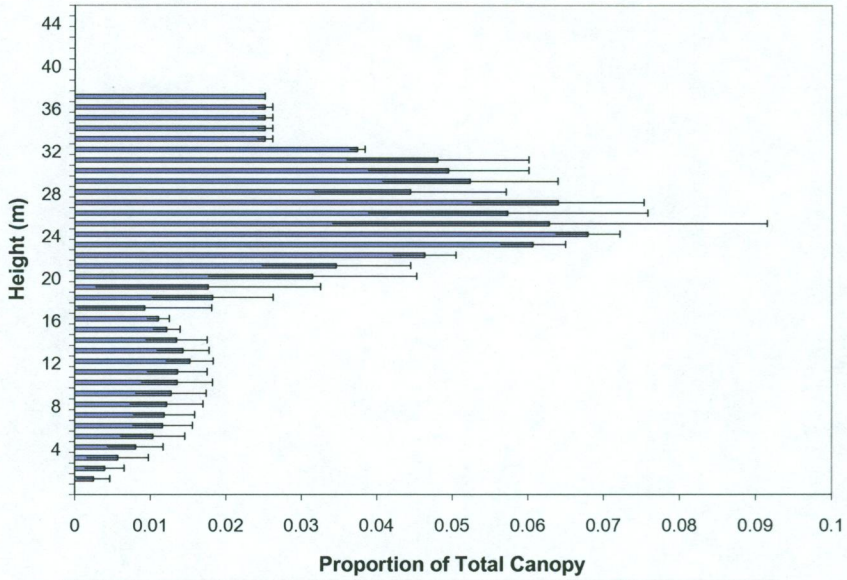
MBR's forests include a range of vertical conditions as defined by canopy layering, based on analysis of foliage height distributions for all reference stands. Figure 14 shows three such conditions, a single-layered un-thinned plantation, a two-layered plantation, and a multi-layered mature hardwood forest. These are representative of the Park's diversity of canopy structures, although reference stands fall along a continuous spectrum, ranging from single to multi-layered, making finer distinctions regarding canopy architecture unclear in some instances.

A trend shared by several stands was the initiation of canopy differentiation (i.e. development of sub-canopies) caused by disturbances, either anthropogenic in the case of thinned plantations or natural in the case of stand #45 (Figure 14, middle). Under both scenarios, reduction in overstory density increased light levels near the ground, leading to accelerated understory re-initiation of shade-tolerant species and subsequent vertical development of two or three layered canopies. Thus, low intensity forestry in the Park appears to have mimicked natural disturbance effects to some degree, especially in terms of the vertical response. It is also noteworthy that at least some the Park's oldest plantations are now rapidly developing late-successional structural complexity without human intervention, thanks to natural disturbances and natural stand development processes.

Single-Layered:
un-thinned plantation



Two-Layered:
naturally disturbed,
older plantation



Multi-Layered:
un-managed, highly
productive
hardwood stand

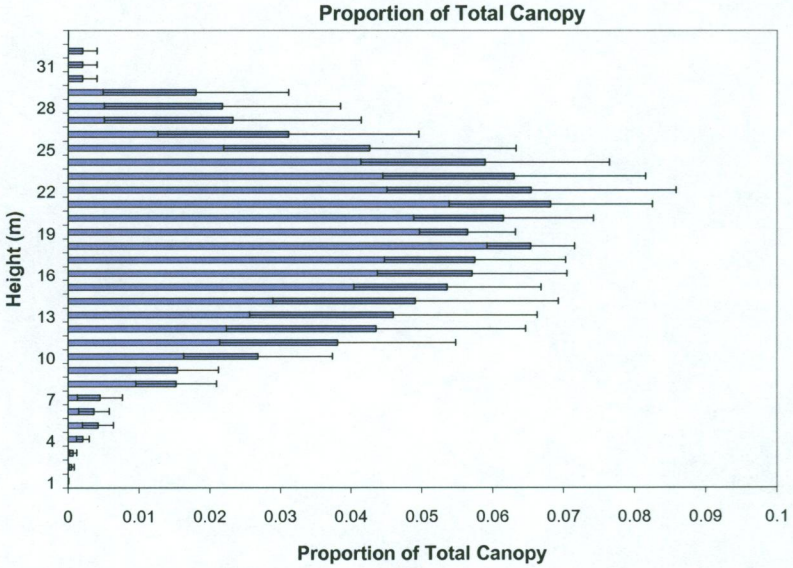


Figure 14. Foliage height distributions for an un-thinned 1950 Norway Spruce plantation (stand #13) (top), an 1880 white pine plantation (stand #45) disturbed by low intensity windthrow (middle), and an unmanaged, uneven-aged, rich northern hardwood stand (stand #30) (bottom). Error bars show +/- one standard error of the mean.

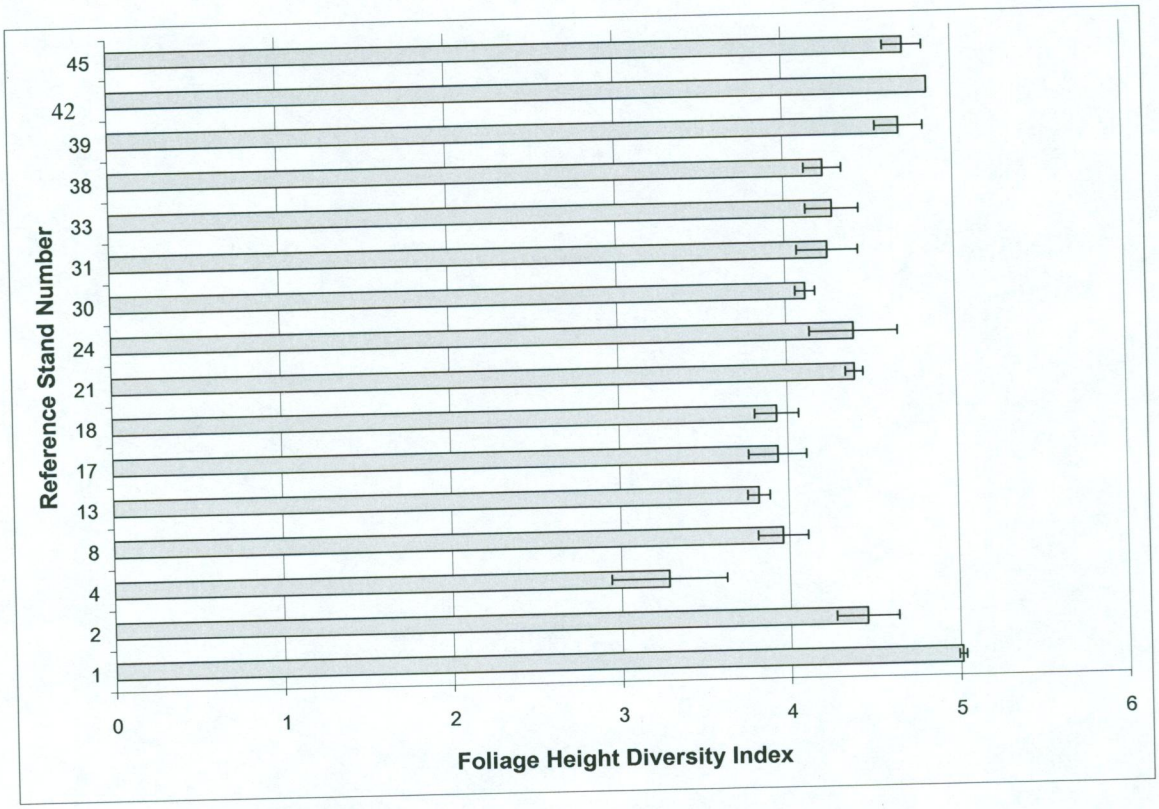


Figure 15. Foliage height diversity index values for all reference stands. Error bars show +/- one standard error of the mean.

Calculation of foliage height diversity index based on the above mentioned distributions provided a means of empirically comparing stands and testing the relationships inferred above. Foliage height diversity index values for reference stands are presented in Figure 15.

There are significant relationships between foliage height diversity and forest management history. Foliage height diversity is significantly higher in stands that have had low intensity silvicultural management (Figure 16), either thinning in the case of plantations (P=0.038) or uneven-aged harvests in the case of semi-natural stands (P=0.038). This relationship holds also when all reference stands are aggregated (P=0.021). Thus, the results suggest that low intensity forestry in the Park has mimicked fine-scale natural disturbances, increasing regeneration rates, releasing advanced regeneration, and generally promoting vertical development.

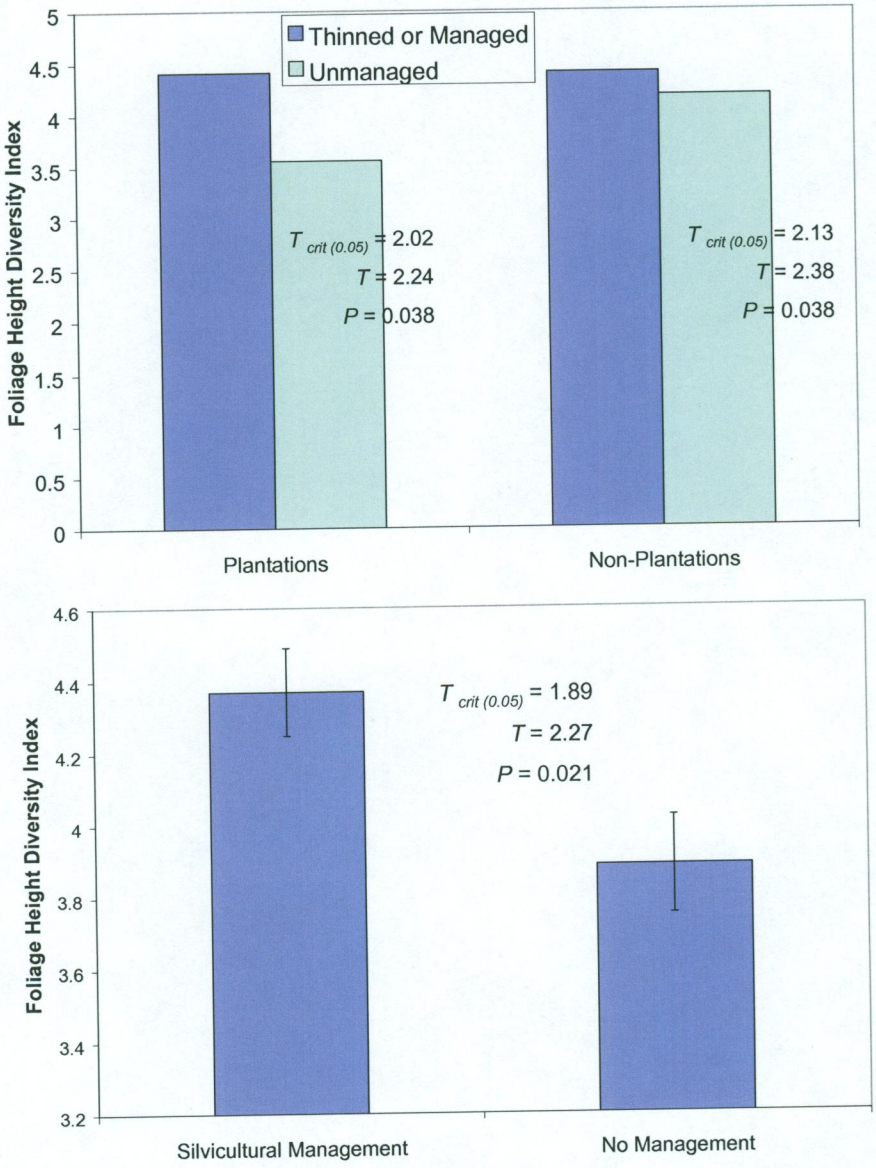


Figure 16. Comparison of foliage height diversity index for plantations and semi-natural stands by silvicultural management regime (above) and for all reference stands (combined) by management regime (bottom). Error bars show +/- one standard error of the mean.

Coarse woody debris

Monitoring results specifically include measures of CWD because it is an important structural feature that influences wildlife habitat, nutrient cycling, tree regeneration, below-ground communities, and other ecological functions associated with forest ecosystem health (Franklin et al. 2002; Keddy and Drummond 1996). Coarse woody debris (CWD) volumes vary substantially throughout the Park. Mean volume and variability data are presented in Table 6.

Table 6. Downed coarse woody debris (>10 cm diameter) data by reference stand.

	Mean Volume (m^3/ha)	Variability (One Standard Error of the Mean)
Stand 1	40.64	17.13
Stand 2	234.98	88.28
Stand 4	13.14	4.78
Stand 8	24.56	10.00
Stand 13	39.17	14.68
Stand 17	31.60	12.44
Stand 18	26.20	8.59
Stand 21	53.77	17.08
Stand 24	14.83	13.53
Stand 30	71.28	24.22
Stand 31	16.93	7.05
Stand 33	5.85	3.80
Stand 38	64.62	26.96
Stand 39	21.45	7.04
Stand 42	11.24	4.59
Stand 45	40.14	24.58

CWD volumes are highest in stand # 2 (Figure 17). This reflects windthrow of large diameter white pine as well as significant accumulation of logging slash from past thinning activity in some areas. Data for that stand significantly bias average volumes estimated for plantations as a group (Figure 18), although volumes are indeed higher in general in the Park's conifer plantations. This may be due to the larger mean diameters in some of the older plantations and the slower decay rates associated with conifer boles. It also may be due to elevated soil acidity in conifer stands, which allows CWD to persist on the ground longer and, thus, accumulate.

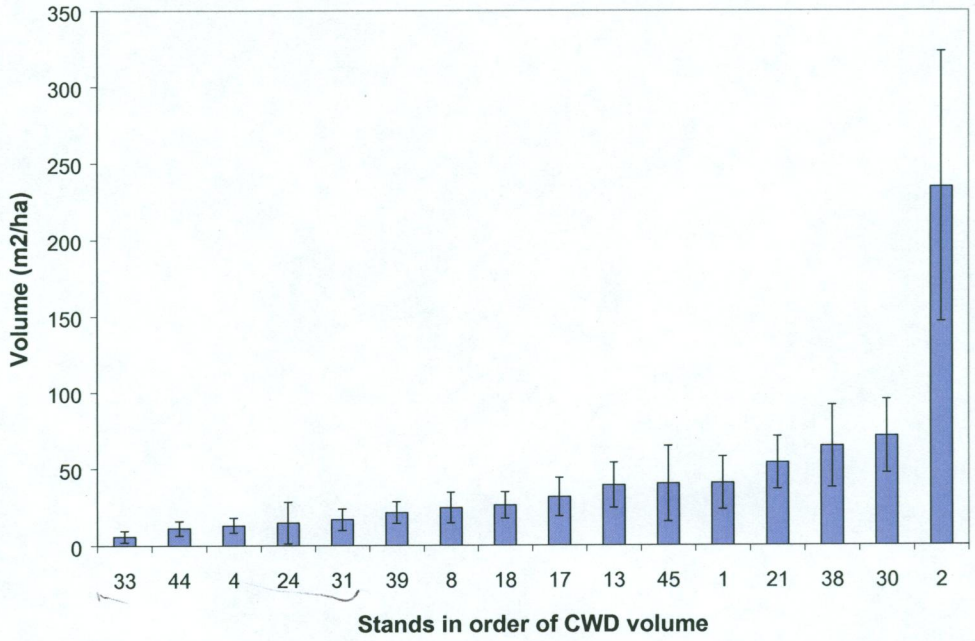


Figure 17. Reference stands ranked by downed coarse woody debris volume.

CWD volumes in semi-natural stands may be below their potential based on comparisons with reference data for mature and old-growth northern hardwood stands in the northeastern U.S. (Tyrrell and Crow 1994a; 1994b; Haney and Schaadt 1996; and McGee et al. 1999). CWD volumes in MBR are less than half the mean values recorded for moderate to highly productive, mature northern hardwood forests throughout the region (Figure 18).

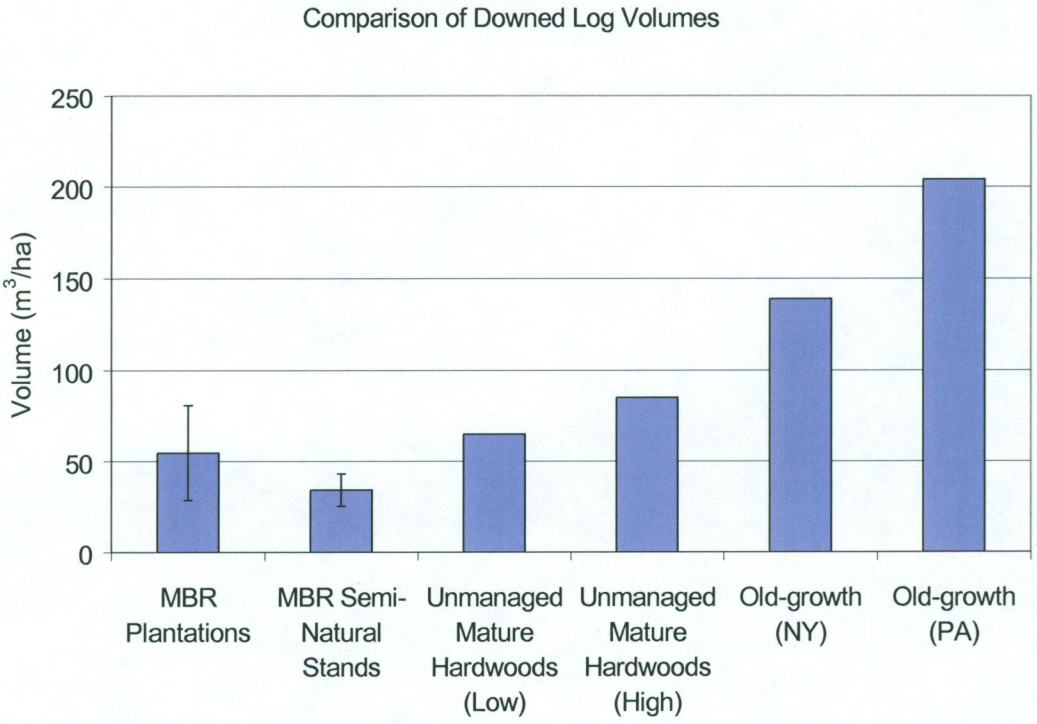


Figure 18. Downed coarse woody debris volumes at MBR as compared to benchmark values for mature and old-growth northern hardwoods in the northeastern United States (benchmark data are from Tyrrell and Crow 1994a; 1994b; Haney and Schaadt 1996; and McGee et al. 1999).

Understory plant communities

The diversity, abundance, and mix of understory plants serve as key indicators of ecosystem integrity. They respond to important stressors, such as off-site impacts from roads and trails, recreational use, acid deposition, exotic earthworms, and noxious invasive plants. The forest monitoring program, therefore, tracks several key understory metrics. They are percent cover, Shannon-Wiener Diversity Index, and species richness at the scale of individual plots.

The forest monitoring system spans a diversity of understory plant communities. A list of species currently found in the monitoring plots is provided as an Appendix (page 35). Data on the three metrics are provided in Table 7. Mean percent cover for all vascular and non-vascular understory plants ranges from 1.97 % (in an un-thinned red pine plantation, stand #4) to 23.27 % (in a 110 year old northern hardwood-hemlock forest, stand #21). The second highest percent cover is in stand #30, an enriched northern hardwood site previously noted for its sensitive and unique (within the Park) botanical attributes (Lautzenheiser 2002; Wiggin 1993). Interestingly, while stand #30 has a high diversity index (2.18), the data suggest that it is second in this regard to stand #42. This

may be an artifact of the non-statistical sample in stand #42 and the stand's narrow shape and adjacency to a clearing, which exposes most of the stand to edge effects. Species richness was highest in stand #30, but was almost as high in a thinned and rapidly developing 1911 white pine plantation (stand #2).

Table 7. Understory plant data by reference stand. Percent cover data are for all vascular and non-vascular understory plants, but do not include tree seedlings. Shannon-Wiener Diversity Index and Species Richness are for vascular understory plants only.

Reference Stand	Percent Cover		Diversity Index		Species Richness at 0.1 ha	
	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
1	2.24	0.92	1.23	0.35	6	3
2	22.35	4.18	1.36	0.26	18	5
4	1.97	0.64	1.14	0.15	5	1
8	5.06	2.22	1.78	0.33	16	5
13	3.08	1.74	0.56	0.30	3	2
17	12.58	2.05	1.43	0.15	11	2
18	15.79	2.52	1.20	0.23	13	3
21	23.27	11.83	1.72	0.36	15	5
24	4.85	2.11	1.23	0.12	8	1
30	22.53	3.65	2.18	0.14	19	4
31	5.28	1.50	1.67	0.21	12	3
33	5.98	2.66	0.82	0.27	9	1
38	17.61	2.94	1.53	0.13	6	4
39	16.69	6.11	1.34	0.24	9	2
42	5.64	na	2.25	na	13	na
45	10.13	6.02	1.74	0.16	12	2

Statistical comparisons of stand groups based on management history indicated that there are strong correlations between low intensity silviculture and both percent cover and diversity index. Percent cover was significantly greater in thinned than in un-thinned plantations (P=0.02). This disparity held true for managed compared to un-managed semi-natural stands as well (P=0.05). Interestingly, while there was a slight, though not statistically significant (P=0.18), difference between plantations and semi-natural stands, there was no difference between thinned plantations and semi-natural stands (P=0.41). Collectively, these results suggest that thinning in plantations has enhanced understory plant abundance and biomass (Figure 19).

Shannon-Wiener Diversity Index values showed similar relationships, with the index higher in thinned vs. un-thinned plantations (P=0.03). The index also differed in comparisons of managed to un-managed semi-natural stands and plantations to semi-natural stands, but these were only significant with $\alpha = 0.10$ (Figure 20).

Exotic plants represented only a small portion of the total percent cover sampled. Exotic species found in the monitoring plots included Japanese honeysuckle, tatarian honeysuckle, Japanese barberry, and European buckthorn. However, in plots where these species occurred, their mean percent cover was < 1% per species. Their distribution appears to be limited and isolated based on plot data. They do not pose a significant threat to native plant communities in the Park at this time. Nevertheless, it will be important to monitor occurrences of exotic species to determine whether their populations expand in the future. This will be particularly important in light of stewardship activities and recreational uses that may or may not facilitate further spread of exotic species.

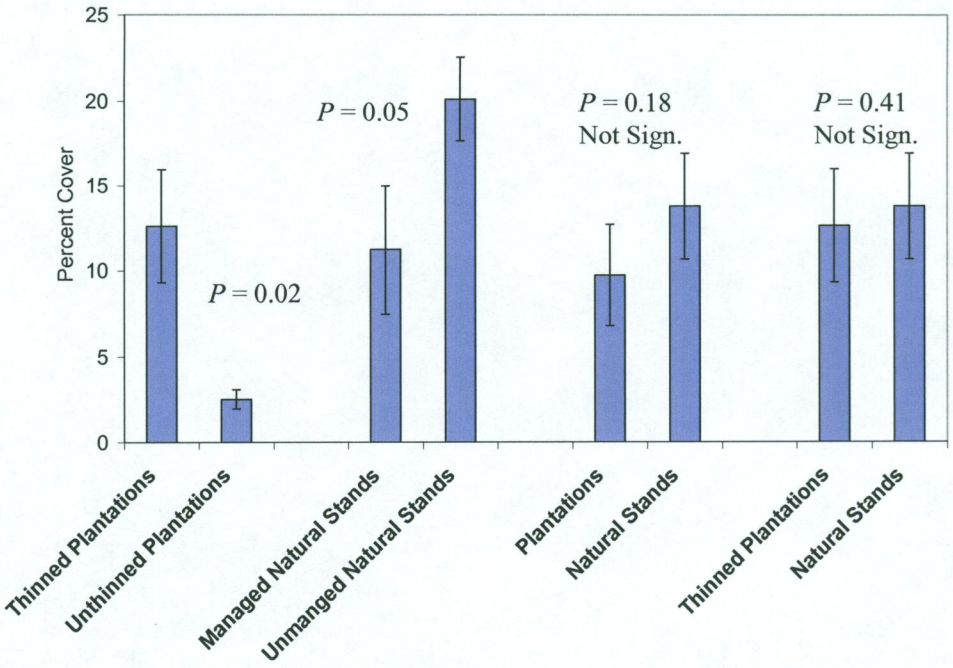
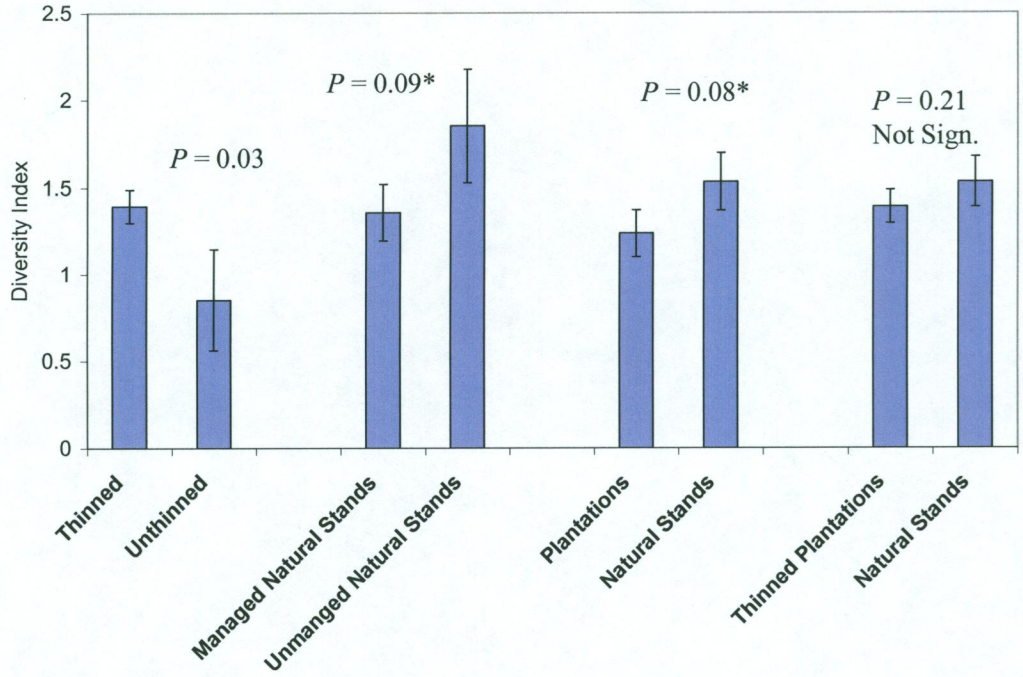


Figure 19. Mean percent cover for understory vascular (shrubs, herbs, and graminoids) and non-vascular (mosses and clubmosses) plants. Lichens and fungi, although sampled, were not included in this analysis. Errors bars show +/- one standard error of the mean. Statistical results are based on T-tests assuming unequal variance. Significance determined at the 95% probability level.



* Significant difference only at the 90% probability level.

Figure 20. Mean Shannon-Wiener Diversity Index, integrating species richness and relative abundance, for understory vascular plants (shrubs and herbs). Errors bars show +/- one standard error of the mean. Statistical results are based on T-tests assuming unequal variance.

Discussion and Conclusions

The forest monitoring program at MBR has been successfully initiated. Results are providing highly informative regarding forest ecosystem conditions and management efficacy. As data are collected, processed, and analyzed over subsequent years, time series will be constructed, allowing direct, rather than inferred, measurements of trends, such as tree growth and forest productivity, and predictive modeling. Additional information on forest health will compliment the analysis to date.

MBR's forests are highly diverse and provide multiple biological and ecological values based on the monitoring results. Mortality rates and regeneration levels appear to be within acceptable ranges. Stocking levels and other forest inventory metrics suggest considerable opportunity for continued demonstrations of sustainable, scientifically informed forest stewardship. Diameter distributions are distinctly multi- to uneven-aged in maturing semi-natural stands. Thus, these stands are appropriate for uneven-aged harvesting systems, including single-tree selection, group-selection, and recently developed approaches, such as structural complexity enhancement (Keeton et al. 2001). Coarse woody debris volumes appear to be in deficit and warrant management attention.

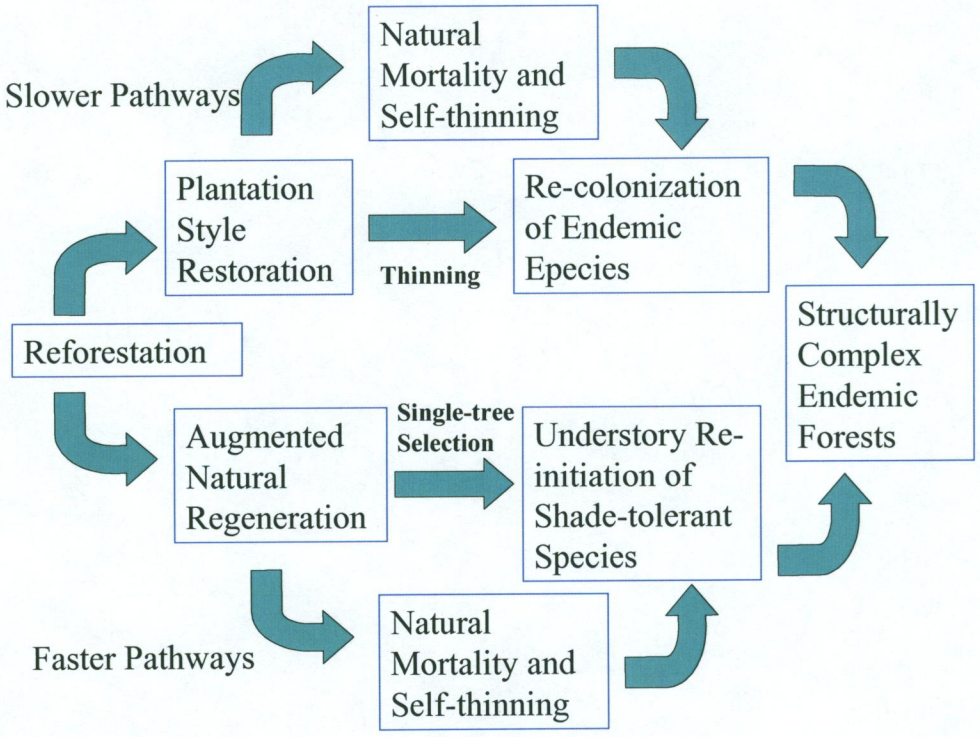


Figure 21. Conceptual stand development model for MBR. The model shows alternate pathways and rates as a function of initial reforestation approach and subsequent silvicultural management.

Overall, stand development processes – influencing myriad functions, such carbon sequestration, structural development and wildlife habitat, and understory plant communities – are robust throughout the Park. However, rates of stand development vary considerably by forest type and silvicultural history. A long history of low intensity forest management on Park lands has accelerated rates of structural development and compositional change. This is most dramatic in the case of plantation thinning, for which almost all monitoring metrics show a significant positive effect on stand development rates. Pathways of development, by contrast, are converging towards locally endemic plant assemblages and late-successional forest structure. This holds true regardless of initial restoration approach, such as conifer plantation versus augmented natural regeneration of mixed species (Figure 21). Figure 21 summarizes these findings in a conceptual model of long-term reforestation processes at MBR.

The monitoring results suggest that restorative silviculural treatments in plantations are highly likely to achieve management objectives where these call for restoration of native or site-endemic species. The results also show, however, that restorative treatments are not necessary in some of the older plantations under-going natural processes of stand development, including low intensity natural disturbances effects. These processes are rapidly moving some areas toward native species restoration.

Finally, it can be concluded from the monitoring results that maintenance of existing plantation composition will be difficult where that continues to be a cultural, historic, or scenic management objective. Plantation maintenance will require careful planning and intensive management inventions, for example understory planting. An adaptive management approach will be essential to achieve this and other forest management and conservation objectives. Continued forest ecosystem monitoring will be an essential component of that approach.

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APPENDIX – Understory Plant Species Found in Monitoring Plots

Scientific Name	Common Name
Grasses	
Agrostis perennans	upland bentgrass
Bromus inermis	smooth brome grass
Cardamine pennsylvanica	common bitter cress
Deschampsia sp.	hairgrass
Glyceria sp.	manna grass
Schizachne purpurascens	swallen grass
Poa sp.	bluegrass
Sedges	
Carex debilis	weak sedge
Carex intumescens	swollen sedge
Carex pedunculata	pedunculed sedge
Carex platyphylla	broad-leaved sedge
Carex sp.	sedge species
Woody Shrubs	
Amelanchier laevis	allegheny service-berry
Berberis thunbergii	japanese barberry
Berberis vulgaris	common barberry
Cornus alternifolia	alternate leaved dogwood
Cornus canadensis	bunchberry
Corylus cornuta	beaked hazelnut
Lonicera canadensis	american fly-honeysuckle
Lonicera japonica	japenese honeysuckle
Lonicera tatarica	tatarian honeysuckle
Prunus virginiana	chokecherry
Rhamnus cathartica	european buckthorn
Rubus allegheniensis	common blackberry
Rubus odoratus	purple flowering raspberry
Rubus pubescens	dwarf raspberry
Rubus sp.	raspberry/blackberry species
Sambucus canadensis	elderberry
Vaccinium corybosum	highbush blueberry
Vaccinium myrtilloides	velvet-leaf blueberry
Viburnum acerifolum	maple-leaved viburnum
Viburnum alnifolium	hobblebush
Vitis riparia	river bank grape

Ferns and Allies

Adiantum pedatum	Maiden-hair fern
Athyrium filix-femina	lady fern
Dennstaedtia punctilobula	hay-scented fern
Deparia acrostichoides	silvery spleenwort
Dryopteris carthusiana	spinulose wood fern
Dryopteris filix-mas	male fern
Dryopteris intermedia	intermediate wood fern
Dryopteris marginalis	marginal wood fern
Equisetum sciroides	dwarf scouring rush
Equisetum sp.	horsetail species
Gymnocarpium dryopteris	oak fern
Matteuccia struthiopteris	ostrich Fern
Onoclea sensibilis	sensitive fern
Osmunda cinnamomea	cinnamon Fern
Osmunda claytoniana	interrupted fern
Osmunda regalis	royal fern
Phegopteris connectilis	long beech fern
Phegopteris hexagonoptera	broad beech fern
Polysticum acrostichoides	christmas fern
Pteridium aquilinum	bracken fern
Thelypteris noveboracensis	new york fern

Herbaceous Plants

Actaea pachypoda	white baneberry
Aquilegia canadensis	wild columbine
Aralia hispida	bristly sarsparilla
Aralia nudicaulis	wild sarsparilla
Arisaema atrorubens	jack-in-the-pulpit
Asarum canadense	wild ginger
Asclepias syriaca	common milkweed
Aster acuminatus	whorled aster
Aster sp.	aster species
Boehmeria cylindrica	false nettle
Caulophyllum thalictoides	blue cohosh
Circaea alpina	dwarf enchanter's nightshade
Clintonia borealis	yellow clintonia
Crepis capillaris	smooth hawksbeard
Dicentra candensis	squirrel corn
Eupatorium rugosum	white snakeroot
Fragaria vesca	wood strawberry
Fragaria virginiana	wild strawberry
Galium tinctorium	bedstraw
Galium triflorum	fragrant bedstraw
Geranium bicknellii	bicknell's cranesbill
Geranium robertianum	herb robert
Hepatica acutiloba	sharp-lobed hepatica
Hieracium aurantiacum	devil's paintbrush
Hieracium vulgatum	common hawkweed
Hypericum perforatum	common st. johnswort
Impatiens capensis	jewel weed
Laportea canadensis	wood nettle

Maianthemum canadense	canada Mayflower
Mitchella repens	partridgeberry
Orchidaceaa unknown	unknown orchid
Oryzopsis asperifolia	white-fruited mountain rice
Osmorhiza claytonii	sweet cicely
Polygala paucifolia	fringed polygala
Polygonatum pubescens	hairy solomon's Seal
Potentilla simplex	common cinquefoil
Prenanthes alba	white lettuce
Pyrola asarifolia	pink pyrola
Pyrola elliptica	shinleaf
Pyrola secunda	one-sided pyrola
Rananculus fuscicularis	early buttercup
Ranunculus repens	creeping buttercup
Saxifraga virginiensis	early saxifrage
Solidago flexicaulis	broad-leaved goldenrod
Solidago sp.	goldenrod species
Streptopus amplexifolius	twisted stalk
Streptopus roseus	rosy twisted stalk
Taraxacum officinale	common dandelion
Tiarella cordifolia	heart-leaf foamflower
Trientalis borealis	starflower
Trillium erectum	red trillium
Trillium sp.	trillium species
Uvularia sessilifolia	sessile-leaved bellwort
Veronica officinalis	common speedwell
Veronica spp.	speedwell
Viola sp.	violet species