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# Forestry Across Borders

## Proceedings of the New England Society of American Foresters 84th Winter Meeting

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Shelterwood seed cut in northern hardwoods. Photo by Mark Twery.

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# FORESTRY ACROSS BORDERS

## Proceedings of the New England Society of American Foresters 84th Winter Meeting

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**Edited by**

**Jeffrey S. Ward and Mark J. Twery**

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# TREE CONDITION CHANGES AND THE 1998 ICE STORM

**Kenneth M. Laustsen**[†]

## Introduction

The January 1998 Ice Storm impacted to some degree over 11 million acres in Maine. In order to prioritize recovery, the Maine Forest Service (MFS) contracted for large-scale, high-resolution photography and interpretation of damage on over 2 ½ million acres. This large-scale polygon mapping delineated eight damage levels, ranging from none to heavy.

## Objective

Analyze whether the photo-interpreted damage polygons are reflected in either the frequency or magnitude of tree condition changes since 1995.

## Methods

MFS supplied a shape file of damage level polygons to the USDA Northeastern Research Station (NERS) for an overlay and assignment of the exact P2 (FIA) plot location to a specific damage level. NERS returned to MFS a database containing the plot id information and the respective damage level code for all 5 panels.

The Maine Forest Service funded a separate data collection of equivalent P2 data on 493 plots over the period of 2001-2003. A sample of 392 plots are linked with an Ice Storm damage level and the available plot sample area is a 19/120-acre fixed area annular ring, inside and concentric to the 1995 1/5-acre plot area.

Aggregating the eight photo-interpreted damage levels created four generalized damage groupings. That aggregation and the resultant sample size is as follows:

1. None (includes None) – 149 plots
2. Trace (includes Zero – Trace) – 95 plots
3. Light (includes Trace – Light, Light, Light – Moderate) – 78 plots
4. Heavy (includes Moderate, Moderate – Heavy, and Heavy) – 70 plots

Tree condition is a two-stage coding stratification. The first stage identifies whether a tree is alive, dead, or a snag, and the second stage characterizes the condition of the tree's top as being a intact live top, intact dead top, broken top, or down. This analysis considered only live trees, ≥ 5.0″+ DBH, tallied in 1995 and then remeasured by MFS in 2001 - 2003.

Transition tables were developed, collapsing the multiple combinations of initial tree condition (1995) and current condition reflecting any Ice Storm damage, into just four distinct groups:

1. Tree Condition Improved
    - Initial live tree, intact dead top - Current live tree, intact live top
    - Initial live tree, broken top - Current live tree, intact live top/intact dead top
2. Tree Condition Maintained
    - Initial live tree, intact live top - Current live tree, intact live top
    - Initial live tree, intact dead top - Current live tree, intact dead top
    - Initial live tree broken top - Current live tree, broken top
3. Tree Condition Degraded (Still Live)
    - Initial live tree, intact live top - Current live tree, intact dead top/broken top
    - Initial live tree, intact dead top - Current live tree, broken top
4. Tree Condition Degraded (Dead)
    - Initial live tree, intact live top/intact dead top/broken top - Current dead tree, intact top/broken top/down or a Current snag, intact top/broken top

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## Results

In 1995, the frequency distribution of initial tree condition, by the damage groupings, is similar regardless of the pending 1998 Ice Storm (Table 1). Live trees with an intact live top represent 96% of the available 9,186 live trees.

**Table 1.—Frequency distribution of 1995 initial tree condition, by ice storm damage grouping.**

| Ice Storm Damage Grouping | Tree Condition Class<br>Live Tree Intact Live Top | Live Tree Intact Dead Top | Live Tree Broken Top | Total |
|---|---|---|---|---|
| None | 95.9% | 3.1% | 1.1% | |
| Trace | 95.6% | 3.5% | 0.9% | |
| Light | 96.6% | 1.8% | 1.6% | |
| Heavy | 97.3% | 1.3% | 1.4% | |
| Overall | 96.2% | 2.5% | 1.2% | 100% |

The increasing intensity of the Ice Storm damage is reflected in the gradual erosion of trees that maintained their tree condition coding over the approximately 7-year period (Table 2). The None and Trace groups maintained tree condition on 87% of the sample trees, compared to 84% for the Light group and 81% for the Heavy damage grouping. The damage inflicted by the 1998 Ice Storm within the Light group mainly resulted in a 2% higher increase in dead trees compared to the two lesser damage groupings. The Heavy damage grouping had the most change in the transition category of Tree Condition Degraded (Still Live), with at least a 4 percent increase over the other three categories. Finally, compared to the minor damage groupings of None and Trace, the Heavy grouping also had at least a 1% increase in dead trees.

**Table 2.—Transition category and the distribution of change, by ice storm damage grouping.**

| Ice Storm Damage Grouping | Transition Category<br>Tree condition Improved | Tree condition Maintained | Tree condition Degraded | Tree condition Dead |
|---|---|---|---|---|
| None | 1.1% | 87.4% | 4.3% | 7.2% |
| Trace | 2.0% | 87.0% | 2.9% | 8.1% |
| Light | 1.1% | 84.5% | 4.5% | 9.9% |
| Heavy | 1.4% | 81.1% | 8.3% | 9.2% |

## Conclusions

The current FIA annualized inventory design can provide an alternative, consistent, and accurate analysis of damage inflicted by various disturbances. The tree level analysis of tree condition can be structured to assess the immediate damage and more importantly, the long-term implications of this damage to the tree's growth and product quality potential.

# INITIAL RESULTS IN MEASURING HEMLOCK WOOLLY ADELGID POPULATIONS IN TREES AND FORESTS

**Alexander Evans**†

## Abstract

An invasive exotic insect, the hemlock woolly adelgid (HWA) (*Adelges tsugae*) has caused widespread mortality of eastern hemlock trees (*Tsuga canadensis*) and threatens to extirpate the species from North American forests (McClure et al. 2001, Orwig et al. 2002). HWA-induced mortality is a concern because hemlocks provide important forest structure, habitat, economic benefits, and aesthetic values (Beatty 1984, Kelty 1989, DeGraaf et al. 1992 p. 92, Snyder et al. 2002). Neither HWA population densities nor their distribution in forests is well understood, hampering the ability of forest managers to respond to the pest. No published studies have described the distribution of HWA in tree crowns or within forest stands (Gray et al. 1998, McClure and Cheah 1999, Adams et al. 2002, Casagrande et al. 2002, Mayer et al. 2002). In addition, standard monitoring methods have inestimable bias and provide limited results. Lacking better information, land managers often have to assume that HWA is evenly distributed and saturates the environment.

The goal of this research is to create better monitoring methods and estimates of HWA densities that can help forest managers mitigate the pest's negative impacts. The first step is the development of a sampling system appropriate to the biology of HWA. The second phase is a survey of HWA densities in a New England forest. Early results from sampling suggest that there is little pattern to HWA's distribution within individual trees, upper and lower portions of the crown are infested at similar densities. However, there are differences between HWA populations on trees in neighboring forest stands. While, final results of the study are not yet available, other research may benefit from the methodology and initial trends documented here.

## Methods

My hypothesis is that HWA populations per needle differ between stands within a forest, but not at the scale of individual trees. I suggest that HWA populations do not vary systematically within tree crowns or between trees within the same stand. However, HWA populations do differ across a forest at the scale of several hundred meters. To test my hypotheses, this research compares estimates of HWA populations in different parts of hemlock crowns, between trees, and between stands by sampling HWA in naturally infested forests. Sampling HWA is complicated by its small size, lack of pheromones, and tree crown habitat. I have modified the randomized branch sampling (RBS) methodology to estimate HWA per needle in hemlock crowns (Jessen 1955, Gregoire et al. 1995). RBS treats a tree as a series of paths from the ground to each terminal shoot. Under RBS the researcher randomly selects a path to a terminal shoot and the characteristics of interest, number of HWA and needles in this case, encountered along this path become part of the sample. The RBS path can be terminated at any branching node to allow sampling of entire branches. The path is created by a series of random selections at each node. In other words, at each fork in the branch the researcher randomly chooses which branch to follow. The researcher can adjust the probability of selecting a branch to increase the likelihood of sampling more of the quantity of interest, so long as the probabilities at any particular fork sum to one. No design bias is introduced if the selection remains probabilistic. The inverse of the product of the unconditional selection probabilities for a sample is used to inflate the sample to an estimate for the whole tree. RBS provides an operationally efficient mechanism for unbiased estimation of both the mean and variance of the quantity sampled (Gregoire et al. 1995).

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I have altered my sampling scheme to include the simple random selection of the first node to more efficiently deal with the branching pattern of hemlock, while retaining an unbiased design. After felling the sample tree, I divide the crown into thirds and take at least three samples from each third. My preliminary sample of 16 trees from four stands suggests that there is little difference between crown thirds, nor does there appear to be a difference in the number of HWA per needle between trees in the same stand. All four stands are hemlock / hardwood mixtures about 80 to 100 years of age on the Yale Myers forest in Union, CT, within 2 km of each other. Initially counts included only HWA eggsacks. Now counts also include the most recent generation of HWA (sistens) on new growth as a more time sensitive measure of HWA density. Table 1 below shows the number of HWA eggsacks and HWA sistens per 100 needles at specified height ranges above the ground.

**Table 1.—HWA eggsacks and sistens per 100 needles at specified heights above the ground.**

| Height above the ground | HWA eggsacks per 100 needles | | | HWA sistens per 100 needles | | |
|---|---|---|---|---|---|---|
| | Median | Mean | Maximum | Median | Mean | Maximum |
| 5m – 9.9m | 0.0 | 2.5 | 14.1 | 53.2 | 53.4 | 146.0 |
| 10m – 14.9m | 0.0 | 4.5 | 31.2 | 44.9 | 43.8 | 150.0 |
| 15m – 19.9m | 0.3 | 4.6 | 31.7 | 1.6 | 10.9 | 79.2 |
| > 20m | 0.6 | 9.4 | 43.9 | 20.5 | 28.1 | 78.1 |

Further sampling will allow for a Tukey-Kramer test for differences between the HWA densities in crown strata. Similarly more sampling is required to test for differences in HWA densities between stands. Preliminary sampling suggests that stands 2 and 4 are different from stand 3 and perhaps stand 1, as shown in Table 2 below.

**Table 2.—HWA eggsacks per 100 needles in four different stands.**

| Stand | Median | Mean | Maximum |
|---|---|---|---|
| 1 | 0.4 | 3.0 | 23.2 |
| 2 | 0.0 | 0.4 | 10.4 |
| 3 | 12.0 | 13.3 | 43.9 |
| 4 | 0.0 | 0.5 | 7.7 |

Comparison of the HWA populations in different stands in the forest requires a method for unbiased selection of the trees sampled. Since the randomize branch sampling employed in this study is a destructive sampling scheme, I have selected trees based in part on the possibility of safely felling them. In order to remove the constraint of sampling only easy-to-fell trees, sampling for stand differences will take advantage of commercial timber harvests at the Yale Myers Forest. Randomly selected trees will be pre-marked, safely machine felled, and then sampled for HWA. A random sample of trees from different stands will allow unbiased estimates of HWA per needle in each stand.

## Conclusions

Early results show that randomized branch sampling is an effective way to sample for HWA and that HWA densities may vary more from stand to stand than within a tree or between neighboring trees. If continued research confirms these results it will suggest that differences in stand conditions have an effect on HWA populations, which may have implications for hemlock survival.

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# CROP-TREE RELEASE INCREASES BLACK BIRCH DIAMETER GROWTH

**Jeffrey S. Ward**[†]

Black birch (*Betula lenta*) is an increasing component of the southern New England forest where it currently accounts for nearly 7% of sapling and pole trees. In Connecticut, black birch cubic-foot volume has increased 64% since 1972. Because it had been a minor component of the forest until recently, there have been few studies that have examined its growth rate following release.

Crop-tree management (complete release) is one possible method of concentrating growth on individual stems of high value species (Perkey and Wilkins 1994). The concept is similar to weeding in a garden. Crop-tree management increases growth of selected trees by releasing moisture, nutrients, and light that had been utilized by less desirable trees. The rationale of crop-tree management is that limited management resources are best allocated to higher quality trees. Crop-tree thinning increases the value of the future stand by concentrating growth on individual high value trees. Crop-tree release is risky because management effort is concentrated on relatively few stems (Trimble 1974). Therefore, care should be taken in selecting high quality trees.

A precommercial crop-tree study established in 1988 found that relative to unreleased trees, crop-tree release increased diameter growth of black birch by 52% (Ward 1995). Smith and Lamson (1983) also reported that black birch growth increases following release. These studies indicated that further research was warranted on the influence of release on black birch growth. Therefore, research was begun in 1996 to determine how crop-tree release affects diameter and crown growth of black birch, and whether crop-tree release affects potential sawtimber quality.

## Methods

In 1996, four crop tree plots were established in cooperation with Division of Forestry-CT DEP, Metropolitan District Commission, the Regional Water Authority, and Northeast Utility Forest Management Lands in cooperation with Ferrucci and Walicki, LLC (Table 1). A fifth plot was established in Suffield in 1997 on Northeast Utility Forest lands. All plots were fully stocked and had not been thinned for at least 20  years.

**Table 1.—Initial stand and tree characteristics in a black birch crop tree study in Connecticut.**

| Plot | Diameter (inches) | Stand age (years) | Year released |
|---|---|---|---|
| Tunxis | 4.8 | 20 | 1996 |
| Saltonstall | 5.1 | 20 | 1996 |
| Suffield | 8.9 | 51 | 1997 |
| Tariffville | 11.3 | 43 | 1996 |
| Barkhamsted | 13.8 | 99 | 1996 |

At least 60 crop trees were selected at each plot (317 trees total). Selection criteria for crop trees were codominant or dominant crown class, at least 17 ft to first fork, and potential grade 1 or 2 buttlog. Crop trees were banded at 4.5 feet and systematically numbered with red paint. Diameters were recorded to the nearest 0.1 cm (0.04 inches). Diameter measurements were taken with a diameter tape and repeated each year during the dormant season. Cookies were cut from at least six stumps on each plot after harvesting. Tree ages were determined from ring counts of the cookies after they were dried and sanded.

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The trees were split into two groups: trees 1-30 and trees 31-60. A coin flip determined which group was released on each plot. Release was completed as part of a thinning operation on all plots after the 1996 growing season. Tunxis was a noncommercial operation. The remaining trees that competed with selected crop trees (crowns within 3 feet of crop tree crown) were either felled or girdled. Trees on the Suffield plot were released after the 1997 growing season. For the preliminary analysis, plots were split into three groups: small poles (Tunxis and Saltonstall), large poles/small sawtimber (Suffield/Tariffville), and sawtimber (Barkhamsted).

## Results and Discussion

Black birch has responded well to release (Table 2). Black birch on the small poles plots responded immediately to release. Diameter grow of released trees increased 75% the first year compared with unreleased controls. This increased growth has been maintained for 7 years. During this period, released poles have gained an additional inch in diameter. Diameter growth of large poles/small sawtimber was also increased by crop-tree release, albeit after a lag period of several years. Diameter growth since the third year after release has average more than 0.1 inches/year greater than for unreleased large poles/small sawtimber – roughly double that of the control trees.

**Table 2.—Mean annual diameter growth (inches) of black birch released on four sides (crop-tree) vs. no release (control) by size class in Connecticut.**

| | Years since initial release | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Mean |
| | Small poles | | | | | | | |
| Crop-tree (n=62) | 0.29 | 0.35 | 0.21 | 0.25 | 0.32 | 0.23 | 0.26 | 0.27 |
| Control (n=64) | 0.16 | 0.19 | 0.10 | 0.14 | 0.15 | 0.11 | 0.14 | 0.14 |
| Difference (%) | 75% | 83% | 118% | 82% | 110% | 113% | 83% | 92% |
| | Large poles/small sawtimber | | | | | | | |
| Crop-tree (n=63) | 0.18 | 0.21 | 0.18 | 0.23 | 0.30 | 0.22 | 0.22 | 0.22 |
| Control (n=64) | 0.17 | 0.18 | 0.10 | 0.11 | 0.16 | 0.11 | 0.14 | 0.14 |
| Difference (%) | 6% | 21% | 72% | 100% | 92% | 98% | 64% | 60% |
| | Sawtimber | | | | | | | |
| Crop-tree (n=31) | 0.06 | 0.20 | 0.22 | 0.05 | 0.18 | 0.18 | 0.21 | 0.16 |
| Control (n=33) | 0.09 | 0.16 | 0.12 | 0.07 | 0.13 | 0.15 | 0.13 | 0.12 |
| Difference (%) | -36% | 24% | 88% | -32% | 46% | 26% | 61% | 31% |
| | Combined size classes | | | | | | | |
| Crop-tree (n=156) | 0.20 | 0.27 | 0.20 | 0.20 | 0.29 | 0.22 | 0.23 | 0.23 |
| Control (n=161) | 0.15 | 0.18 | 0.10 | 0.12 | 0.15 | 0.12 | 0.14 | 0.14 |
| Difference (%) | 39% | 48% | 93% | 75% | 92% | 86% | 72% | 70% |

The influence of crop-tree release on larger sawtimber black birch has been erratic and harder to assess. Growth response during the first 3 years was similar to that for the large pole/small sawtimber trees (i.e., slowly increasing). However, during the fourth year after release, diameter growth of released trees sharply declined for an unknown reason. Subsequently, diameter growth of released sawtimber trees has been greater than for unreleased controls. Over the 7-year period of this study, crop-tree release has increased diameter growth of sawtimber black birch by 0.04 inches/year.

This study found that black birch, especially trees with diameter less than 11 inches, respond well to complete release. This suggests that crop-tree management may be a valuable management in areas with a high proportion of black birch. Further research will be needed to assess stand growth rates of black birch using various silvicultural systems.

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# STRUCTURAL CHANGES IN THE NEW ENGLAND LANDSCAPE DURING THE LAST 100 YEARS

**Joseph P. Barsky**[†]

During the last century, many changes have occurred to forests across New England. Current forest conditions are the expression of past activities and cultural practices. An emphasis of forest research has been identifying the condition of each state's forest resources. The USDA Forest Service has conducted Forest Resource Inventories for each state at regular intervals since the late 1940s. During each inventory cycle, a wide range of data was collected to create a snapshot of forest conditions. From time to time, components of the inventories have been tabulated (Baldwin 1949, Irland 1982). Few studies have focused in assembling data from those inventories at a regional level to obtain a chronology of the changes during the last century, and correlate it with lumber production values for the same period. In this study, select data from every inventory of each state was assembled to depict a century of change across New England.

## Methods

For this study, a majority of the data was in dissimilar formats. Therefore, several assumptions were necessary to develop a consistent set of data. First, the algorithms used by the USDA Forest Service to analyze data were different during each inventory. Values from a given inventory year were seldom the same when they are re-presented in subsequent publications, due to changes in processing technique. For consistency and expediency, values from the most current publication were used. Second, values were averaged between inventory periods when there was a gap in the data. Therefore, sudden changes would not be apparent in the summary presented in this note. Third, changes in nomenclature during the last century present another difficulty. Consistent standards were not established until c.1948. As a result, values before that time were examined carefully within the context of the reference, and then used or modified where appropriate. Data for each state has been assembled individually, and then compiled on the regional scale. A full list of the sources used are given in References.

## Results and Discussion

Many changes were observed during the last century to the forest cover in New England (Table 1) and the lumber it has yielded (Table 2). The principle finding was that there were nearly 6 million more acres of forest land at the end of the century than were present at the beginning of the century. Most of this increase occurred prior to 1950. For the past 50 years (1950-1995), total forest area in New England has remained stable.

**Table 1.—Average Forested Acres (in thousands) by Stand-Size Class in New England**

| Decade | Non/seed/sap | Poletimber | Sawtimber | Total[1] |
|---|---:|---:|---:|---:|
| 1910-1919 | 3,870 | 11,466 | 9,901 | 25,237 |
| 1920-1929 | 6,451 | 7,865 | 11,911 | 26,226 |
| 1930-1939 | 8,374 | 5,696 | 13,339 | 27,409 |
| 1940-1949 | 8,488 | 8,185 | 13,483 | 30,156 |
| 1950-1959 | 5,998 | 14,104 | 10,723 | 30,825 |
| 1960-1969 | 6,709 | 13,759 | 11,026 | 31,495 |
| 1970-1979 | 6,985 | 11,302 | 12,998 | 31,284 |
| 1980-1989 | 4,137 | 11,237 | 16,103 | 31,476 |
| 1990-1995[2] | 5,021 | 11,345 | 14,564 | 30,930 |

[1] Stand size values may not equal Total due to rounding.
[2] Values after 1995 were not available.

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Another important observation is that lumber production has steadily increased during the same period, and hardwood values became a significant component. Several factors contributed to these conditions. Harvest levels dropped during the first half of the century as forest area increased. Softwood lumber was a vital component of several industries at the turn of the last century, and as those areas were exhausted, many stands converted to hardwoods. In addition, hardwood poletimber was widely used for fuel during that time, and those areas quickly resprouted. Those areas are now largely mature and are being removed at levels approaching those of 100 years ago.

**Table 2.—Average reported lumber production (billion board-foot measure) in New England.**

| Decade | Hardwood | Softwood | Total |
|---|---|---|---|
| 1900-1910 | 3.3 | 19.2 | 22.5 |
| 1910-1919 | 3.0 | 14.2 | 17.2 |
| 1920-1929 | 1.9 | 6.7 | 8.5 |
| 1930-1939 | 0.9 | 3.9 | 4.8 |
| 1940-1949 | 1.4 | 8.1 | 9.6 |
| 1950-1959 | 2.9 | 10.0 | 12.8 |
| 1960-1969 | 4.1 | 9.3 | 13.3 |
| 1970-1979 | 6.1 | 11.1 | 17.2 |
| 1980-1989 | 7.2 | 12.6 | 19.9 |
| 1990-1999[1] | 7.3 | 12.9 | 20.3 |

[1] adjusted to a 10-year basis

## Conclusion

Assessing change at a regional level yields a different set of information that would not be noticeable at the local level. Forestry, as a science, was in its infancy 100 years ago in New England. Then, as now, challenges exist, though the focus and size has shifted. Notwithstanding those changes during the last century, none have changed as much as the level of knowledge surrounding it. It is that thought which must guide us through this century.

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# UNDERSTORY HEIGHT GROWTH DYNAMICS IN UNEVEN-AGED, MIXED-SPECIES NORTHERN CONIFER STANDS

**Andrew Moores[†], Robert Seymour, and Laura Kenefic**

## Introduction

There is a great deal of interest in maintaining complex mixed-species, uneven-aged stands in forestry today. These stands provide many non-timber values by conserving important ecological characteristics of the forest. High productivity is also important, as it is key to meeting timber supply objectives. Growth efficiency (GE) in uneven-aged stands, defined as stemwood volume increment per unit of foliage, is maximized by maintaining a high proportion of the stand leaf area in the overstory where tree-level GE is highest (Seymour and Kenefic 2002). Growth efficiency however has been demonstrated to decline with age (Seymour and Kenefic 2002). This presents a tradeoff in managing uneven-aged northern conifer stands where the species of interest, red spruce (*Picea rubens* Sarg.), balsam fir (*Abies balsamea* (L.) Mill), and eastern hemlock (*Tsuga canadensis* (L.) Carr.) are all shade tolerants capable of surviving and responding to release after prolonged periods of suppression in highly shaded understories (Godman and Lancaster 1990; Seymour 1992). If their advancement through the understory is delayed by highly stocked upper strata, future GE potential of these stands could ultimately be reduced. To balance the need for well-stocked upper strata with timely progression of trees through the understory, one must quantify the relationship between overstory density and understory height growth.

The purpose of this study was to explore the growth dynamics of understory trees in uneven-aged, mixed-species northern conifer stands dominated by balsam fir, red spruce, and eastern hemlock. The objectives were to 1) model sapling height growth of these three species as a function of overstory density; and 2) use these relationships to determine maximum overstory densities that facilitate adequate understory height growth.

## Methods

Four mixed-species stands under uneven-aged management were used in this study. Two stands were operated on a 5-year cutting cycle while two stands were operated on a 10-year cutting cycle. All four stands are part of the long-term USDA Forest Service experiment on the 1540-ha Penobscot Experimental Forest (PEF) in east-central Maine. The PEF is owned by the University of Maine.

### Sampling Scheme

The sample for this study included 60 saplings per species equally divided between three height classes of 0.5-2 m, 2-4 m, and 4-6 m for a total sample of 167 trees (there were deficits in the two larger red spruce height classes). These trees were distributed throughout the four stands in order to evenly span the range of available light conditions. Open and closed conditions were represented on an equal basis, to the greatest extent possible. Saplings were excluded if they were growing on poorly or very poorly drained soils, if there was evidence of cutting within the last five years within 5.6 m of the tree, or if the overstory surrounding the sapling contained a large component of hardwoods.

### Data Collection

Canopy closure was measured by taking a gap fraction measurement (DIFN) directly above each sample tree using a LI-COR LAI-2000 Plant Canopy Analyzer (LAI-2000) (LI-COR Inc., Lincoln,

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NE) between mid-August to mid-September in 2002. Gap fraction is the proportion of canopy openness (where 1.0 represents full canopy openness and 0.0 represents full canopy closure), which is achieved by comparing a below-canopy diffuse light reading with a simultaneous reading taken in the open. Height growth measurements (the first five internodal distances) were taken for each sample tree between mid-August and late September in 2002.

### Data Analysis

Average annual height increment (AAHINC) was calculated by summing the measured internodal distances and dividing by the number of nodes. Several linear and non-linear models were used to predict AAHINC for each species using initial height (IH) and DIFN as predictor variables (Table 1). The following alternative hypotheses of height growth response with respect to increases in gap fraction were tested: 1) a linear increase, 2) a curvilinear monotonic increase, and 3) a peaking pattern at intermediate gap fraction values. The models were fit using SYSTAT v.10.2 (Systat Software Inc., Richmond, CA), with alpha=0.05.

**Table 1.—Linear and nonlinear regression models tested to predict balsam fir, red spruce, and eastern hemlock height growth from initial height and gap fraction.**

| Hypothesis | Model |
|---|---|
| 1 | $AAHINC = b_0 + b_1\ DIFN + b_2\ IH$ |
| 2 | $AAHINC = b_0 * DIFN^{b1} * (IH)^{b2}$ |
| 3 | $AAHINC = b_0 + b_1 DIFN + b_2 DIFN^2 + b_3\ IH$ |

## Results

### Annual Height Growth Models

Both IH and DIFN were significant in predicting sapling height growth for all three species. Monotonically increasing power functions of height growth with respect to DIFN best modelled height growth for all three species (Table 2).

**Table 2.—Best fit regression model and corresponding $R^2$ value for each species describing sapling height growth as a function of initial sapling height and gap fraction.**

| Species | Best fit model | $R^2$ |
|---|---|---|
| Balsam fir | $AAHINC = 0.270 * (DIFN1)^{0.607} * (IH)^{0.344}$ | 0.681 |
| Red spruce | $AAHINC = 1.289 * \exp[-1.822 * (DIFN1)^{-0.238} * (IH)^{-0.173}]$ | 0.702 |
| Eastern hemlock | $AAHINC = 0.174 * DIFN1^{0.309} * (IH)^{0.275}$ | 0.502 |

## Discussion

The findings of this research demonstrate that overstory canopy closure, defined as gap fraction, significantly affects height growth of balsam fir, red spruce and eastern hemlock saplings in uneven-aged, mixed-species northern conifer stands. For saplings up to 6.0 m tall, height growth continues to respond positively to decreases in overstory competition until conditions of full canopy openness are met. Average conditions of canopy closure in these stands significantly reduce the rate of height growth, and prolong the time it takes for saplings to reach heights of 6.0 m compared to even-aged stands. Model predictions show that balsam fir, red spruce and eastern hemlock can grow from heights of 0.5 m to 6.0 m in approximately 35-45 years under average understory conditions in these stands. This is a delay of about 15-20 years compared to a red spruce tree growing in an even-aged stand of site index 50 (Carmean *et al.* 1989).

While sapling height growth is reduced in these stands, they are still capable of advancing from seedlings and small saplings to larger saplings and pole-sized trees beneath well stocked, efficient overstories which are also simultaneously producing stemwood volume. This is an important benefit of uneven-aged management and this trade-off with reduced sapling height growth should be considered in any silvicultural decisions. Non-timber objectives are also important benefits of uneven-aged management that offset the reductions in sapling height growth.

The monotonically increasing nature of the best models for sapling height growth makes it difficult to suggest any particular goal for overstory density to balance the trade-off between efficient overstory leaf area allocation and sufficient sapling height growth. It is apparent, however, that gains in the advancement of saplings through the understory are progressively reduced as higher levels of canopy openness are obtained.

## Acknowledgments

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# IDENTIFYING AND ENRICHING FOR AMERICAN BEECH TREES THAT ARE RESISTANT TO BEECH BARK DISEASE

Jennifer L. Koch† and David W. Carey

Beech bark disease begins when bark tissues attacked by the scale insect (*Cryptococcus fagisuga* Lind.) are rendered susceptible to infection by fungi of the genus *Nectria*, leading to the weakening and eventual death of the tree. Some American beech (*Fagus grandifolia*) trees remain disease free in stands long-affected by beech bark disease and challenge trials have shown that they are resistant to the scale insect (Houston, 1982). Increasing the number of resistant beech trees while reducing the proportion of susceptible trees is currently thought to be the best management approach to minimize the overall impact of beech bark disease (Mielke et al. 1986). However, even in heavily infested areas, trees that remain clear of scale may be "escapes" and not truly resistant. We have set out to design a research program with two related goals; 1) to determine if the artificial inoculation technique (Houston, 1982) is an efficient way for distinguishing between resistant and susceptible trees and 2) to develop methods to propagate resistant trees once identified, through both vegetative techniques and cross-pollinations. The following is a summary of our research progress to date.

## Identifying Resistance

Previous work by David R. Houston reported the development of a technique to artificially infest beech with the beech scale (Houston 1982). This technique was successfully used to artificially infest seedlings as young as one year old and to confirm the resistance of older scale-free trees. However, appropriate tests to determine whether this technique could successfully distinguish between resistant and susceptible juvenile root sprouts and seedlings are needed.

### Field trials

Insect eggs or adult, egg-laden insects were collected from foam traps that were put in place the previous year (2002) and used to set up field challenge experiments at both the Allegheny National Forest (ANF) in Pennsylvania and Ludington State Park (LSP) in Michigan. A cluster of 12 putatively resistant trees was included in the ANF study along with 2 susceptible controls. In LSP, a cluster of 20 putatively resistant trees was challenged along with a cluster of 8 susceptible trees. The DBH of the trees ranged from 2.4 to 10.3 inches. In both areas, the clusters of trees appeared to be root sprouts originating from the same parent source. Tissue samples taken from each individual tree will be used to extract DNA and, using molecular markers, determine which individuals are truly clonally identical. Fifty adult, egg-laden insects (average of 8-10 eggs per adult) or 500 individual eggs were counted out and placed onto moistened polyurethane foam pads that measured 4 inches x 4 inches. The pads were placed up against the bark and tied into place. The number of reproductive scale colonies established will be determined in the summer of 2004. By looking at clonal replicates of varying size and age, an indication of the amount of variability produced using the artificial challenge technique will be determined.

### Seedlings

An artificial challenge experiment using both full- and half-sib seedlings has also been set up. The crosses and resulting seeds will be discussed in additional detail in the next section. The challenge experiment is being performed cooperatively with the Holden Arboretum in Kirtland, Ohio. A total of 438 six-month old seedlings were challenged. Polyurethane foam pads measuring 1 inches x 3 inches were moistened and either 30 egg-filled adults or 300 individual eggs were counted out and placed on the foam prior to adhering it to the stem of each seedling. Six weeks after the pads

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were put into place, a handful of seedlings from susceptible parents were checked and crawlers had already hatched from the eggs and attached to the bark. However, not until summer of 2004 will the seedlings be inspected for the presence of reproductive scale colonies.

## Propagating Resistant Beech

To minimize the impacts of beech bark disease, it is necessary to have a source of resistant American beech to be used in pre-emptive plantings ahead of the disease front as well as for restoration of aftermath forests. Our efforts have focused both on vegetative means of propagation and sexual reproduction. Techniques involving vegetative propagation are critical for preserving superior, resistant trees. However, for long term success, it is necessary to maintain genetic variability as well as disease-resistance.

### Softwood cuttings

Softwood cuttings were taken from candidate resistant trees at LSP in late May, 2003, at the beginning of leaf emergence. Cut stems were soaked overnight in either a solution of 1.2 mM IBA in water or 1.2 mM IAA in .02 N NaOH. After the overnight soak, they were placed in rooting media (3 parts sterile play sand, 2 parts perlite, and 1 part Rediearth) and kept under mist. Roots began to sprout after 21 days and after 30 days . However, in order to allow maximum root growth the cuttings were not transplanted until 60 days. Unfortunately, by this time root rot had set in and a number of cuttings were lost. Table 1 shows the number of rooted cuttings that achieved new shoot growth. By optimizing the rooting media and misting protocol for maximum drainage and by potting rooted cuttings earlier we are hopeful that the percent of successful rooted cuttings will be greatly improved.

**Table 1.—Success rates of softwood cuttings of American beech.**

| Treatment | Rooted (%) | Shoot growth (%) |
|---|---|---|
| IBA | 22 | 38 |
| IAA | 53 | 19 |

### Open-Pollinated Seeds

Open-pollinated seed was obtained from two of the parents used in the cross-pollinations study, the resistant tree 1506 and the susceptible tree 1504. Open-pollinated seed was also collected from the susceptible tree 1511 and from a resistant tree located in Maine. The tree from Maine is of particular interest because it is located in a region that has been intensely managed for beech bark disease—susceptible trees have been removed. Therefore, there is a significant chance that the seeds from this tree are derived from resistant pollen donors. Between 24-35% of the seeds collected from trees at Ludington State Park (1506, 1504, and 1511) were full. This figure is only slightly higher than the reported 13 - 29% of sound nuts collected from 20 trees in East Lansing, MI (Gysel, 1971). The percentage of seeds collected from the Maine tree that were sound was much higher (75%) than those collected from Ludington State Park. This value was comparable to the values reported by Leak & Graber (1993) for seed collected from beech in the White Mountain National Forest. Over a 6-year period of time seeds from this area were consistently between 75 and 88% sound. The lower number of sound seed collected in Michigan, compared to those collected in Maine, may be attributable in part, to the fact that Ludington State Park is toward the northern most border of the natural range of American beech.

### Cross-Pollinated Seed

The results of the controlled cross-pollinations are listed in Table 3. Overall, the germinative capacity (the percent of sound seed that germinated) was variable, ranging from 12 to 84 percent.

However, compared to open-pollinated seeds from this study, the average germinative capacity of cross-pollinated seeds was greater. The percent of barren seed was similar in both the cross-pollinations and the open-pollinations, with the exception of the 1504 ♀x 1506 ♂cross which produced a slightly lower, 13% sound seeds. This similarity between cross-pollinated and open-pollinated seed production provides an indication that the pollination bagging process did not negatively effect seed development. The production of a lower percentage of sound seed in the 1504♀x 1506♂cross could possibly be attributed to an incompatibility between the parents or that 1504 does not produce vigorous pistillate flowers. Open-pollinated 1504 flowers produced seed with a low germinative capacity and the two controlled crosses that used 1504 as the maternal parent produced seed with lower germinative capacities compared to seeds from crosses that used 1505 or 1506 as the maternal parent. Differences in compatibility between pairs of parents is not uncommon and identifying compatible mating pairs is an important part in developing seed orchards for tree improvement (Lambeth 1993).

**Table 2.—Controlled cross-pollinated seed**

| Cross (♀x ♂) | Seeds | | | | | | Germinative Capacity | Total No. Plants |
|---|---|---|---|---|---|---|---|---|
| | Full | Germinated | Rotten | Empty | Total | %Full | | |
| 1506 (S) x 1504 (R) | 11 | 84 | 0 | 146 | 241 | 39 | 81 % | 77 |
| 1504 (R) x 1506 (S) | 49 | 31 | 10 | 585 | 675 | 13 | 12 % | 11 |
| 1504 (R) x 1501 (I) | 35 | 0 | 0 | 98 | 133 | 26 | 37 % | 13 |
| 1505 (R) x 1504 (R) | 28 | 33 | 0 | 170 | 231 | 26 | 84 % | 51 |

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# CROWN RADIUS MODELS FOR EASTERN WHITE PINE

**G.J. Jordan[†] and M.J. Ducey**

Using data from 449 trees on 69 growth and yield plots located in southern and central New Hampshire, we developed models of crown radius for stand-grown eastern white pine (*Pinus strobus* L.) in New Hampshire. In addition to DBH, we tested single-tree measurements sometimes collected in forest inventories (such as total height and live crown length). We also tested variables easily derived from forest inventory data that would correct for stand density and competitive position, including basal area per acre, mean tree spacing (calculated from trees per acre) and DBH/QMD. The addition of basal area per acre, DBH/QMD, and mean tree spacing as independent variables provided only minor improvements over a simpler model that predicts crown radius as a linear function of DBH alone. The addition of basal area per acre provided the largest improvement in prediction of crown radius versus the model with only DBH.

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# MANAGING STANDS OF MIXED NORTHERN CONIFERS: 40-YEAR RESULTS FROM THE PENOBSCOT EXPERIMENTAL FOREST

**Paul E. Sendak†, John C. Brissette, and Robert M. Frank**

## Abstract

This long-term experiment in Maine was designed to provide information on the best silvicultural practices for managing stands of mixed northern conifers in northeastern North America. We evaluated growth and yield and changes in species composition, quality, and structure during the first 40 years of the experiment. Replicated treatments include the selection system, uniform shelterwood, unregulated harvesting, and diameter-limit cutting. The new cohort established under three-stage shelterwood was subsequently left untreated or precommercially thinned. Between-treatment differences in net volume growth were not significant ($\alpha = 0.10$), though gross volume growth differed managed vs., unmanaged, selection vs. shelterwood, and shelterwood vs. diameter-limit treatments. The three-stage shelterwood method with precommercial thinning 10 years following final overstory removal resulted in good control of hardwoods and hemlock and a large increase in the proportion of spruce and fir. The selection system on a 5-year cutting cycle resulted in an increase in hemlock, spruce, and fir, with a decrease in hardwood species. If the primary goal were production, even-aged management would most likely be preferred. We recommend two-stage shelterwood as applied in this experiment with some modification to improve species composition and stand quality. Stand quality (proportion of stand volume in cull trees) and species composition were influenced by treatment.

## Introduction

The experiment reported here represents a half-century of effort by a number of USDA Forest Service researchers. This report covers the first 40 years of the study representing about one-half of a sawtimber rotation for even-aged red spruce (*Picea rubens* Sarg.) stands in the northeastern U.S. At the time that this experiment was established, there were thousands of hectares of clear-cut and partially cut stands of mixed northern conifers in the northeastern US cut primarily for their spruce and fir timber. Westveld (1953) proposed an approach to managing these forests based on ecological principals advocating the selection system as the preferred option in most spruce-fir stands. Heavily influenced by Westveld's ideas, this study was designed to provide information on the best silvicultural practices for managing operable and developing stands of mixed northern conifers. Our analysis was based on an experiment established from 1952 to 1957 on the Penobscot Experimental Forest (PEF) in east-central Maine.

This report evaluates volume growth and yield, changes in species composition, quality, and to a limited extent, structure of mixed northern conifer stands managed under eight different silvicultural techniques for a period of 40 years. The study experiment primarily was designed to study treatments applied to operable stands. However, precommercial thinning was applied to a portion of the new stand resulting from one of the treatments. The main hypothesis tested was that growth and yield was affected by treatment. Changes in species composition and stand quality and structure were examined but not subject to statistical testing.

## Materials And Methods

### Site Description

The 1619-ha Penobscot Experimental Forest is located near Bangor, ME. The treatments were installed on approximately 170 ha located in the northern half of the PEF. The PEF is located in the Acadian Forest, an ecotone between the eastern broadleaf and boreal forests. Mixed northern

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conifers dominate the PEF, including mostly red spruce, balsam fir (*Abies balsamea* (L.) Mill.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), northern white-cedar (*Thuja occidentalis* L.), and eastern white pine (*Pinus strobus* L.). The most common hardwoods are red maple (*Acer rubrum* L.) and paper birch (*Betula papyrifera* Marsh.). The predominant cover types on the research compartments were red spruce-balsam fir and eastern hemlock (Eyre 1980). The study area is predominantly spruce-fir flat, characterized by thin, shallow, often wet soils. The research compartments were mostly classified as somewhat poorly to poorly drained and mediocre in productivity.

## Long-term Study

Replicated treatments, established from 1952 to 1957 include the selection system on 5- (S05), 10- (S10), and 20-year (S20) cutting cycles, uniform shelterwood with two- (SW2) and three-stage (SW3) overstory removals, unregulated harvesting (URH), and two variations of diameter-limit cutting, fixed limits (FDL) and modified limits (MDL). The new stand established under three-stage shelterwood was subsequently left untreated or precommercially thinned (SW3p). The experiment also included an unmanaged natural area (NAT). A network of 307 systematically located permanent points (with random start) was established. Measurements were taken before and after each cutting treatment and approximately every 5 years following each harvest. Species, DBH, and condition were recorded on plots. Volume, cull volume, basal area, growth, number of trees, mortality, species composition, and diameter distribution were determined from the plot data. Yield was calculated as the difference between pre- and post-harvest inventories. Each compartment was managed as a unit and commercially logged by an independent logging contractor. Volume growth was the principal concern of the study. One-way analysis of variance was used to test the hypothesis of no difference between treatment means for net volume growth, gross growth, accretion, ingrowth, and mortality. A series of planned comparisons of treatment means for net and gross volume were part of the statistical analysis. Details of the study can be found in Sendak et al. (2003).

## Results and Discussion

The ANOVA of net volume growth indicated no difference between treatment means (Table 1). Gross volume growth for the MDL and NAT treatments was greater than that for the SW3p and SW3 treatments. Pairwise comparisons between similar treatments (i.e., the two diameter limits, three selection treatments, and three shelterwood treatments) showed no differences between treatment means.

For accretion in volume, there was a significant difference between the two extremes: MDL with the greatest accretion and SW3 with the least (Table 1). For ingrowth, there was a difference between SW2 with the greatest ingrowth and SW3p and SW3 with the least. For mortality, there were no significant differences between treatment means. Differences between treatment yields from the harvested compartments were not significant ($\alpha = 0.10$). Overall mean harvested volume for the study was 171.7 $m^3$ $ha^{-1}$, which does not include the zero harvest in NAT.

Average annual net growth in volume on the PEF based on 40-year data was $2.6 \pm 0.2$ $m^3$ $ha^{-1}$. The results indicated that the average of all treatments on the PEF was statistically the same as what might be expected regionally, $2.9 \pm 0.1$ $m^3$ $ha^{-1}$, in natural extensively managed stands (Safford 1968). For the first 40 years of the experiment, harvests have been of trees that were there before 1950. In most treatments, they have been removed in two or three cuttings, but for some, like S10 and S05, removals were extended through several cuttings during the period. The next few cycles of cuts (in 5 to 20 years) in most treatments will probably be the first to harvest trees regenerated during the experiment. Future comparisons of net growth may show that some treatments will achieve greater net growth in volume. This is especially true for the even-aged treatments.

**Table 1.—Average annual growth in volume ($m^3\ ha^{-1}\ yr^{-1}$) by components and treatment in order of decreasing net growth for trees >11.4 cm DBH.**

| Treatment | Accretion | Ingrowth | Gross growth | Mortality | Net growth |
|---|---|---|---|---|---|
| S05 | 3.21ab | 0.58ab | 3.79ab | 0.40 | 3.40 |
| MDL | 3.64a | 0.62ab | 4.27a | 0.99 | 3.27 |
| FDL | 3.12ab | 0.73ab | 3.85ab | 0.80 | 3.05 |
| S20 | 3.06ab | 0.48ab | 3.54ab | 0.74 | 2.79 |
| S10 | 3.02ab | 0.69ab | 3.71ab | 0.99 | 2.72 |
| SW2 | 2.30ab | 0.86a | 3.16ab | 0.63 | 2.52 |
| SW3p | 2.32ab | 0.34b | 2.66b | 0.40 | 2.25 |
| SW3 | 2.10b | 0.41b | 2.51b | 0.41 | 2.09 |
| URH | 2.29ab | 0.67ab | 2.96ab | 0.95 | 2.01 |
| NAT | 3.56ab | 0.21ab | 4.08a | 2.49 | 1.59 |

Note: Means followed by the same letter within a column are not significantly different by Tukey method ($\alpha = 0.10$). Means in columns with no letters are not significantly different. S05, 5-yr selection; MDL, modified diameter-limit; FDL, fixed diameter-limit; S20, 20-yr selection; S10, 10-yr selection; SW2, two-stage shelterwood; SW3p, three-stage shelterwood with precommercial thinning; SW3, three-stage shelterwood; URH, unregulated harvest; NAT, natural area.

After 40 years, the experiment represents about half a sawtimber rotation for an even-aged stand in the Acadian Forest. As the even-aged stands regenerated in the shelterwood treatments begin to mature, questions about commercial thinning strategies need to be answered. Are specified *BDq* goals in the uneven-aged treatments still appropriate or do they need to be revised? What is the best way to control hemlock reproduction to decrease the proportion of hemlock?

If production were the primary goal of management, some form of even-aged management would most likely be preferred. A recommendation, based on analysis of the treatments in this experiment so far, would be two-stage shelterwood as applied on the PEF, but with the addition of removing all remaining trees >5-6 cm DBH during the final overstory harvest to eliminate competition from overtopping residual trees. Precommercial thinning should also be considered as the new stand develops, depending on density and species composition objectives. The treatment should result in good to excellent control of species composition and percentage of cull volume, which would have a positive effect on revenue. The cost to apply this treatment would be moderate compared with the other treatments. If favoring spruce over fir was an important management objective, removing the overstory in more than two cuts, and thereby releasing the new cohort more slowly, may be worthwhile.

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# THE EFFECTS OF ALTERNATIVE DIAMETER-LIMIT CUTTING TREATMENTS: SOME FINDINGS FROM A LONG-TERM NORTHERN CONIFER EXPERIMENT

**Laura S. Kenefic[†], John C. Brissette, and Paul E. Sendak**

## Abstract

Partial harvests in which only large and valuable trees are removed have long been common in the United States and Canada. These types of cuttings often have degrading effects on residual stand condition, though there is little data on the topic. Fortunately, modified and fixed diameter-limit and commercial clearcutting, as well as the uneven-aged silvicultural system of selection, have been applied by the USDA Forest Service on the Penobscot Experimental Forest in Maine for over 50 years. Results suggest that the degree of degradation, and thus potential for future management, are affected by both the removal criteria and the number of previous harvests. Treatment differences were not great following a single harvest. However, repeated applications of fixed diameter-limit and commercial clearcutting resulted in residual stands that were similar to one another in some aspects of structure and composition, and distinct from selection and modified diameter-limit cut stands.

## Introduction

High-grading is a common practice in which the most valuable trees are removed from a forest stand. This is often applied as diameter-limit cutting. This practice involves the use of a specific size threshold, or diameter limit, above which all merchantable trees are cut and below which no trees are harvested. Though this approach is easy to apply and often maximizes current volume and value production, inattention to residual stand condition can result in degradation (Kenefic et al. in press, Nyland in press). An alternative has been suggested in which high-risk trees below the diameter limits are cut, capturing mortality and upgrading quality in the lower size classes. This is called modified or flexible diameter-limit cutting (see Miller and Smith 1993).

Another common type of exploitative harvest is commercial clearcutting. This should not be confused with silvicultural clearcutting. The latter is an even-aged regeneration method in which all trees are removed in order to regenerate from seed, stump sprouts, or root suckers. Commercial clearcutting is simply the harvest of all merchantable trees from a stand. Alternatively, this may be viewed as a diameter-limit removal in which the size threshold for removals is the lowest limit of merchantability. This type of harvest thus differs from diameter-limit cutting as described above in terms of the volume, but not quality, of trees removed.

Though there is a great deal of anecdotal evidence regarding the effects of these practices, few long-term field studies have been conducted. Recently completed papers by Kenefic et al. (in press) and Nyland (in press) establish the effects of fixed diameter-limit cutting relative to the selection system over multiple cutting cycles. However, little is known about the different types and intensities of diameter-limit removals, and the effects that these have on residual stand conditions. The objective of this study was to assess the effects of selection and diameter-limit cutting alternatives over multiple harvests in northern conifers.

## Study Area

The stands sampled in this study are part of a long-term silvicultural experiment on the 4000-acre Penobscot Experimental Forest in east-central Maine. The most common species on the forest are eastern hemlock (*Tsuga canadensis* (L.) Carr.), balsam fir (*Abies balsamea* (L.) Mill.) and spruce (*Picea* species). Research began in 1950 when the USDA Forest Service initiated an experiment to study even- and uneven-aged silvicultural systems and exploitative cutting. Treatments and remeasurements have continued to the present and follow a long-term study plan. The eight stands

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used for the research reported here are two replicates each of selection (SC), modified diameter-limit (MDL), fixed diameter-limit (FDL) and commercial clearcutting (CC). Average stand size for these treatments is 27.2 acres, with a range of 17.7 to 43.2 acres.

### Treatments

The SC treatment utilized a BD*q* structural goal with a *q*-factor of 1.4 on 1-in. diameter at breast height (dbh) classes, residual maximum diameter of 16 in. dbh, and residual basal area (BA for trees ≥ 0.5 in. dbh) of 80 $ft^2$/acre. Treatments were applied in years 0, 20, and 40 of the experiment. Marking guidelines were used to prioritize removals in order to improve stand quality and growth. Species composition goals, expressed as a percentage of stand BA, resulted in efforts to increase the proportion of spruce and decrease balsam fir and eastern hemlock.

The MDL treatment was applied at years 0, 20, and 40 of the experiment. All merchantable trees above species-specific diameter limits were removed at each entry, unless desired for seed or wind protection. Trees below the diameter limits were harvested as needed to capture future mortality. The size thresholds used for removals in the first entry were 10.5 in. dbh for eastern white pine (*Pinus strobus* L.), 9.5 in. for spruce species and eastern hemlock, and 7.5 in. for paper birch (*Betula papyrifera* Marsh.). All merchantable trees of other species were removed. The volume removed in subsequent harvests was limited to net periodic growth, and diameter limits were raised prior to the second and third harvests (see Sendak et al. 2003). The minimum merchantability threshold was lowered in this and other treatments from 6.5 in. dbh in year 0, to 5.5 in. in year 20, and 4.5 in. in year 40.

The FDL treatment was applied three times, at years 0, 20, and 40 – 45 of the experiment (there was a 5-year time lag between replicate treatments for the third cut). All merchantable trees above species-specific diameter limits were removed. Size thresholds for removal were 11 in. dbh for eastern white pine, 9 in. for spruce and eastern hemlock, and 8 in. for paper birch and northern white-cedar (*Thuja occidentalis* L.). All merchantable trees of other species were removed. Over the course of the experiment the diameter limits varied ±1.0 in. from the above diameters. The study plan specifies that the treatment be applied when the volume available for harvest equaled that removed in the initial entry.

The CC treatment was applied twice, at years 0 and 30 of the experiment. All merchantable trees were removed and the stand was re-entered when initial harvest volume had regrown.

## Methods

Nested 1/5- and 1/20-acre plots were established in each stand on a systematic grid with a random start in year 0 of the experiment. Overstory data were collected on these permanent fixed-radius plots before and after every harvest and at about 5-year intervals between harvests. Trees ≥ 0.5 in. dbh were numbered and species, dbh, and condition (merchantability) were recorded on the 1/20-acre plots. On the 1/5-acre plots, the same data were recorded for trees ≥ 4.5 in dbh. These plots provide an approximately 15% sample of each treatment. Between-treatment comparisons of overstory data were made in years 0 and 40 using analysis of variance (degrees of freedom (df); model=3, error=4) and Bonferroni pairwise comparsions ($\alpha = 0.10$). The analysis reported here included five variables: volume, percent cull, percent spruce species, and volumes of harvest and mortality.

## Findings

Application of the partial cutting treatments described above differentially affected stand structure and composition (Table 1). Pre-treatment comparisons of volume, percent cull, and percent spruce species revealed no significant differences. Residual stocking and quality (expressed as percent cull) were not differentiated by treatment after the first harvest. Though there were no treatment differences in mortality or harvested volume over the measurement period (which included three cuts each in MDL, FDL and SC, and two cuts in CC), volume at the end of the period was higher in the MDL and SC than CC and FDL. Differentiation of the treatments into these two groups is supported by the species data, which showed significantly more spruce in the MDL and SC than CC and FDL. Stand quality expressed as percent cull was only different between the SC and FDL treatments.

**Table 1.—Treatment comparisons before and after the first harvest and in year 40[1] of the experiment.[2]**

Table 1a. *Total volume ($ft^3$/ac).*

| | Year 0 (pre) | Year 0 (post) | Year 40 |
|---|---|---|---|
| SC | 2163 | 1604 | 1255 a |
| MDL | 2040 | 1434 | 1455 a |
| FDL | 2095 | 1091 | 464 b |
| CC | 1881 | 821 | 229 b |
| *SE* | 156 | 203 | 93 |

Table 1b. *Percent cull volume.*

| | Year 0 (pre) | Year 0 (post) | Year 40 |
|---|---|---|---|
| SC | 6.3 | 6.8 | 1.2 b |
| MDL | 7.9 | 7.9 | 11.8 ab |
| FDL | 7.3 | 11.1 | 26.2 a |
| CC | 9.2 | 14.3 | 16.7 ab |
| *SE* | 0.9 | 2.2 | 4.4 |

Table 1c. *Percent spruce BA.*

| | Year 0 (pre) | Year 0 (post) | Year 40 |
|---|---|---|---|
| SC | 14.9 | 17.9 a | 30.0 a |
| MDL | 19.6 | 22.8 a | 28.5 a |
| FDL | 21.4 | 19.8 a | 15.0 b |
| CC | 15.3[3] | 7.1 b | 5.6 b |
| *SE* | 2.3 | 1.9 | 2.1 |

Table 1d. *Volume removals.*

| | Harvest ($ft^3$/ac) | Mortality ($ft^3$/ac/yr) |
|---|---|---|
| SC | 2518 | 14.9 |
| MDL | 2434 | 14.1 |
| FDL | 3527 | 11.6 |
| CC | 2775 | 14.1 |
| *SE* | 260 | 3.1 |

[1] Data are post-cut for SC, MDL, and FDL, and 10 years post-cut for CC. Year 45 data were used for one FDL replicate, due to delayed treatment application.

[2] Means followed by the same letter within a column or in columns without letters are not significantly different ($\alpha$ = 0.10, model df = 3, error df = 4). SE = standard error.

[3] Calculated for trees $\geq$ 4.5 in. dbh due to missing sapling data.

## Conclusion

Though more complete analysis is needed to fully understand the effects of these treatments, the data reported here suggest some important findings. Structural effects of the diameter-limit treatments were not distinguishable from SC after a single entry. Yet, multiple entries resulted in quantifiable differences, with less volume and a lower proportion of spruce in FDL and CC stands. Stands repeatedly cut with FDL were also differentiated from SC stands by stand quality (expressed as percent cull). Modified diameter-limit cut stands were similar in structure, composition, and quality to SC stands, even after repeated entries. These findings suggest important differences in the diameter-limit cutting variants, and will be of use to managers and landowners who are faced with decisions about partial cutting alternatives.

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# REHABILITATION OF NORTHERN HARDWOOD STANDS IN SOUTHERN MAINE FOLLOWING EXPLOITATIVE HARVESTS

**Michael Maguire[†] and Laura Kenefic**

Northern hardwoods constitute the most common forest type group in Maine today. Much of this forest is owned by small non-industrial landowners in the southern region of the state, where diameter-limit cutting and high-grading are common. These types of harvests often result in residual stands characterized by poor quality and low vigor trees, less valuable species, and variable stocking and crown cover (Nyland 1992). Silvicultural opportunities for small woodland owners are limited by such conditions. This problem is confounded by the fact that many landowners further degrade or sell their property because poor quality and quantity of timber deter profitable and sustainable management. This is particularly a concern in southern Maine, where land-use pressure is high and forest tracts are predominantly small and privately owned.

Though the negative effects of diameter-limit cutting and high-grading have been documented (Kenefic et al. in press, Nyland in press), research addressing the rehabilitation of degraded stands is scant. Strategies which promote long-term ecological and financial benefits while addressing the financial constraints of small woodland owners must be identified.

The purpose of this study is to compare and evaluate the outcomes of alternative silvicultural treatments following exploitative harvests in southern Maine. Data will be collected from recently harvested northern hardwood stands in the region. Silvicultural treatments will be modeled over a 100-year period using the NE-TWIGS variant of the Forest Vegetation Simulator (USDA Forest Service). These treatments will include control (no treatment), diameter-limit cutting, intermediate treatments, and even- and uneven-aged regeneration harvests. A financial analysis pertaining to timber harvests and residual stand conditions will be compared across treatments and sites, and sustainability of composition, structure and production will be evaluated.

This research will enable us to identify forest practices that allow sustainable, economically viable management of a stand type that is common in the region. The results will provide a valuable tool for landowners and forest managers who seek to manage degraded northern hardwood stands.

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# AN EXAMINATION OF MULTI-BAND MULTI-POLARIZATION RADAR DATA FOR FORESTED WETLAND IDENTIFICATION IN NEW HAMPSHIRE

**Susan E. Campbell†, Mark J. Ducey, William A. Salas**

## Introduction

The ability to identify forested wetlands across the landscape is becoming increasingly important for land managers. They provide habitat for numerous wildlife species and present operational challenges if they can be logged. This poster examines the potential of multi-band, multi-polarization radar data to identify forested wetlands in New Hampshire.

Light based satellite sensors, like Landsat TM, are only able to “see” the uppermost layer of objects. Forested wetlands present a challenge because the forest canopy will hide the water beneath. Red maple (*Acer rubrum*) swamps and upland red maple forests are spectrally similar. Similarly, a forested spruce (*Picea spp.*) wetland would not be spectrally different from a spruce upland forest. The New Hampshire Land Cover Assessment: Final Report (Justice et al. 2002) used the National Wetland Inventory, as a mask to split forested wetlands from upland forest. This method resulted in a producer’s accuracy of 74.3% and a user’s accuracy of 86.7% for forested wetlands identification.

Radar has been found to be useful to study forest biomass (Dobson et al. 1995), inundated floodplains (Townsend, 2002), and swamps (van Zyl et al. 1990). Many studies, like Dobson and Townsend, focused on forested areas that have homogeneous forest canopy types and/or reasonably flat terrain.

In April and October 1994 the Shuttle Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) missions were flown, generating a multi-band, multi-polarization dataset. The data swathes for New Hampshire are being examined for ease in finding forested wetlands. It is expected that the structural and ground information provided by radar may make a radar based classification of forested wetlands at least as accurate as the New Hampshire Land Cover Assessment method.

## Methodology

The New Hampshire forested landscape is heterogeneous containing patches of pure conifer, pure hardwood, and mixed conifer-hardwood forest. The data swathes also cover a varied terrain. Known forested wetlands are being used as training data for the image processing. These are paired with known uplands of the same forested cover-type. These areas will be identified on Landsat TM imagery and the SIR-C imagery. The Landsat TM and SIR-C/X-SAR imagery will then be classified for cover types and the wetlands identified.

Because of the small size of the sample and the region studied the unknown and newly identified wetlands and like upland forest will be located on the ground and confirmed in person. An error matrix (Congalton and Green 1999) will then be created and compared with the error matrix from the New Hampshire Land Cover Assessment: Final Report. If this method proves to be accurate, radar datasets generated by future satellite-based platforms may provide repeated coverage. Multi-temporal studies could then allow not only easy identification of forested wetlands, but also change detection in those wetlands.

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# PRELIMINARY RESULTS FROM A RETROSPECTIVE STUDY OF HARVEST INTENSITY, SITE PRODUCTIVITY, AND RED SPRUCE GROWTH

**Andy Reinmann**[†]**, Laura Kenefic, Ivan Fernandez and Walter Shortle**

## Introduction

Silvicultural treatments are disturbances that affect the availability and distribution of resources on a site. These disturbances can result in accelerated mineralization, nitrification and the mobilization of base cations and metals. If this pulse of mobile cations is recorded in the sapwood, it will provide a mechanism for evaluating historical responses of soils to harvesting disturbance. The objectives of this research are to (1) determine the effects of harvesting intensity on soil and red spruce (*Picea rubens* Sarg.) stemwood chemistry, and (2) define the relationships between measures of soil productivity and red spruce radial growth.

## Methods

This retrospective study is being conducted in the Acadian forest of central and northern Maine on International Paper and Seven Islands Land Company forest land. Six stands with similar site properties and known historical harvest dates and intensities (removals ranging from 30% to >80%) were selected along with two unharvested control sites. Each stand was classified as a softwood stand (at least 75% softwood composition) dominated by red spruce and balsam fir (*Abies balsamea* (L.) Mill) with level terrain and somewhat poorly to poorly drained soils. On each site ten red spruce were randomly selected and cored using a 12-mm increment borer. The O and B horizons of the adjacent soils were sampled.

Dendrochemistry, tree vigor (as expressed by radial increment), and the chemistry of associated soils will be used to quantify harvest-induced changes in soil productivity. Data collection began during the summer of 2003 and will be completed during the summer of 2004. During the first field season all trees were cored and soil samples were obtained from half of the sites (one site representing each harvest intensity and a reference). Soil samples are currently being analyzed and the tree cores are being read, crossdated and prepared for dendrochemical analysis.

## Preliminary Results

**Table 1.—Depth of the O horizon in four stands with different harvest intensities (defined as percent volume removal).**[1]

| Harvest intensity (percent) | Number of samples | O horizon depth (cm) |
|---|---|---|
| 0 | 10 | 2.2 a |
| 30 | 10 | 2.2 a |
| 50 | 10 | 2.4 a |
| 80 | 10 | 1.9 b |

[1] Means followed by the same letter are not significantly different (alpha=0.05). Standard error of the mean = 0.3.

Preliminary analysis of variance using Tukey's studentized range test (HSD) was conducted with SYSTAT v. 10.2 (Systat Software Inc., Richmond, CA). A log transformation was applied to correct for non-normal distribution of the data. Results for O horizon depth from the four sites sampled

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thus far suggest that there is no relationship between depth of the organic material and intensity of harvest, up to 50% removal (Table 1). An increase in harvest intensity to 80% removal shows a significant decrease in O horizon depth. Because pre-harvest soil data are not available, we are unable to determine if harvest intensity is the causative factor in this relationship. Yet, the data are suggestive and warrant further investigation. Further analysis of this and other variables will be conducted when the data are available.

## Conclusion

This is the first study to utilize soil chemistry, dendrochronology and dendrochemistry in a single study of the effects of harvest-associated disturbance on soil productivity. The results will represent a significant advance in our understanding of tree growth and the impacts of harvesting, and will directly contribute to more sustainable management of red spruce dominated ecosystems.

## Acknowledgments

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# VEGETATION DYNAMICS AFTER THE BAXTER PARK FIRE OF 1977

**Erin D. Small†, Jeremy S. Wilson, and Alan J. Kimball**

## Abstract

Fire is widely recognized as an important natural disturbance agent impacting ecosystems throughout the world. Post-fire vegetation dynamics and subsequent management implications substantially differ in each region. Because north central Maine is believed to have a long return interval fire regime (at least 800 years according to Lorimer [1977]), the threat of catastrophic fire in one's lifetime seems remote. However, with an apposite synergy of events, historical evidence supports that severe fires can and do occur in this region.

A series of interacting disturbance events occurred in Baxter State Park in Maine offering an excellent opportunity to study long-term changes in vegetation. In July of 1977, 1439 hectares in and adjacent to Baxter State Park experienced a severe forest fire. Much of the fire burned areas that were blown down in a 1974 windstorm; some of these areas were salvaged prior to the fire, while others were not. Sandra Hansen (1983) set up plots to represent the various stand conditions and measured vegetation composition and structure a year following the fire. The current study will re-establish these plots and document vegetation structure to improve our understanding of forest development after disturbance. Specific research objectives are to: 1) relocate the original plot markers, 2) describe post-fire vegetation development, and 3) evaluate the influence of pre-fire disturbances on the post-fire regeneration process.

## Introduction

Previously viewed as an interruption to nature, fire's effect on forest stand development patterns has been recently credited with playing a key role in ecological processes. While wildland fire ecology is researched throughout many parts North America, it is relatively little studied in the northeastern United States and especially in the Acadian spruce-fir ecosystem where there is a relatively cool, humid climate and seemingly lengthy fire return intervals. Lorimer (1977) postulated a fire regime of at least 800 years for north central Maine. Subsequently, the natural role of fire has been downplayed in this region. Historical records and charcoal evidence indicate that fire activity in Maine does occur with the right combination of weather, fuel, and ignition. In addition, disturbances can interact to create the right conditions for large impacts.

In November of 1974, a synergy of events began with a severe windstorm affecting 2000 hectares in and around Baxter State Park. The wind damage resulted in a considerable fuel accumulation on and above the forest floor. Some blown down areas were salvaged while others were under stricter management constrains and left unsalvaged due to extensive litigation (Scee 1999). In the midst of this court battle two lightning strikes ignited forest fires on Baxter State Park lands in blown down area caused by the earlier windstorm. High winds and limited access made immediate suppression difficult. Over 1400 hectares burned during the next few days both in parklands and on adjoining Great Northern Paper Company lands (Bowen 1978).

Hansen set up plots a year after the fire that represented these six disturbance history categories: b and ba) burned standing; wb) windthrown/burned; wsb) windthrown/salvaged/ burned; u and ua) unburned; wu) windthrown/unburned; and wsu) windthrown/salvaged/ unburned. Two pre-disturbance stand types (second height class represented by the letter a) and each disturbance history category are represented by one stand if unburned and two stands if burned. Five plots were

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randomly located in the 12 stands representing the range of stand conditions and disturbance histories. In total, 60 plots were established.

Hansen placed rebar stakes as plot markers and measured vegetation and soil conditions on each of these plots during the summer of 1978. She found that organic matter depth decreased with an increase in disturbance, and burned plots had a higher soil pH. Results show 24 plant species in the unburned plots were not found in the burned area; notably these included some conifer species and several bryophytes. Eight new species appeared in the burned areas that were not present in the areas unaffected by the fire. The most notable of these were fungi. Bristly sarsaparilla (A*ralia hispida* Vent.) was remarkably common among the burned plots, forming a "sea" of vegetation the first few years following the fire (Kimball, A.J. June 1982, unpublished field notes).

The main objectives of this study are to relocate these permanent plots to track and describe vegetation composition and structure changes since 1978 and to evaluate the influence of the pre-fire stand conditions on the regeneration by comparing the plots within the fire (burned wind thrown areas, those still standing when the fire occurred, and those that were salvaged).

## Plot Relocation

During the fall of 2002 and the spring of 2003, we searched for and located 54 out of the 60 rebar stakes. Due to inaccuracies and imprecision built into hand drawn maps, we devised a method to provide coordinate search points prior to field exploration. Ortho photos of the area were used to locate origins and landmarks. Using recorded azimuths, pacing distances, and clues alluded to in the site descriptions, expected locations of the plots were identified using GIS programs. The coordinates of these positions were downloaded into a GPS which directed searchers to expected locations of plots. A diameter spiral search method was then used to locate the actual plot. By establishing the spatial coordinates for these plot markers, future measurements for a continuation of this study can be facilitated.

## Methods

Once each plot was located and laid out using the rebar stake as the southwest corner of a 10 m x 10 m square, vegetation was tallied during the months of July and August 2003 (the same time of year as in 1978). In the main plots, each tree was identified to species and measured at breast height (or tallied if below breast height). Height, live crown ratio, and canopy position were assessed for a subset of trees in the plot. Subplots, 1 m x 2 m, were nested in each of the four corners of the main plot for the purpose of examining forest floor components, herbaceous plants, and woody shrubs. In addition, a species list was compiled for all species found in the main plot. Dead and downed material (CWD) was examined in three plot sizes depending on diameter. Only the portion of each log that was actually in the plot was measured. Small and large end diameters and length were recorded, as well as decay class (1-4) assigned. Basic field methods were used to measure organic matter depth for each plot.

**Table 1.—Some preliminary results showing average organic matter depth (OM) and dead and downed volume per hectare (CWD) for each disturbance type. Standard deviations (SD) are also recorded**

| Disturbance | OM (cm) | SD | CWD ($m^3$) | SD |
|---|---|---|---|---|
| b | 9.1 | 4.6 | 2900.4 | 50.5 |
| wb | 5.5 | 2.4 | 991.3 | 74.8 |
| wsb | 3.7 | 2.3 | 411.7 | 14.1 |
| u | 15.0 | 4.8 | 496.1 | 54.7 |
| wu | 13.1 | 7.0 | 641.7 | 82.9 |
| wsu | 0.3 | 4.7 | 273.5 | 37.4 |

## Results

Six disturbance history conditions are used as factors in the analyses. Preliminary results show that stands which were wind thrown and left unburned had the highest number of trees per hectare. Conifers, while present in all plots, were still more prominent on unburned sites. CWD volume was greatest in plots that were burned standing (Table 1). Organic matter depth decreased with an increase in disturbance (Table 1). The soil binding lichen, *Dibaeis baeomyces* L.f., was only found in the most disturbed plots (wb and wsb). To make comparisons among factors, multivariate statistical analyses will be accomplished using a variety of methods including: Detrended Correspondence Analysis, Cluster Analysis, or multiple regression techniques. Analyses will concentrate on identifying development patterns in the last 25 years and similarities and differences among disturbance history factors.

## Discussion

Data collected in this study describe the current species composition and structure in each of the stand conditions. Differences between the stands are expected, especially between those that were standing or salvaged prior to the fire, as opposed to stands that were blown down in 1974. Differences in data collected in 1978 compared to 2003 may be significant. Conifer species may have increased at different rates depending on stand condition since 1978.

The Baxter Park Fire of 1977 is an example of a natural fire where the fire's behavior and impacts were modified by a previous disturbance event and human manipulation. The long-term impacts of such fires are important to consider. Sandra Hansen stated the purpose of this study was to "collect baseline data for long-term studies to see vegetation development after a fire and over time" (Hansen 1983). Wind and fire events will occur again in Maine, and some are likely to follow a similar sequence. The effects of these disturbances have been given relatively little attention historically. While the rest of the country has become focused on fire policy and management dilemmas, Maine and the Acadian spruce-fir ecosystem remain in a zone where fire effects are poorly documented.

This research will expand our knowledge about blowdown salvage, fire management, and fire ecology. It may help the park, the state, and other land owners to design future fire policy and make more informed decisions regarding fire suppression. Baxter State Park currently plans to suppress each fire with any measures necessary. They would like more information on the effects of fires, the effects of suppression, and forest development that occurs following a burn.

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# BETWEEN AND WITHIN GENERA COMPARISONS OF MORPHOLOGICAL PLASTICITY FOR *BETULA* AND *ACER* SEEDLINGS GROWN UNDER VARYING LIGHT CONDITIONS

**David S. Ellum[†], P.M.S. Ashton, and G.P. Berlyn**

## Introduction

The ability of genera, or species within genera, to adapt their morphology to compensate for environmental conditions (phenotypic plasticity) contributes to growth characteristics that can lead to success or failure in changing environments. The study of plasticity can give insight into the biological and physical processes that govern successful regeneration and in turn determine future forest composition. The results presented here are part of a larger project we are conducting to develop an index of morphological, anatomical and physiological plasticity for tree species in southern New England forests.

It is generally held that shade-intolerant, early colonizing species demonstrate greater phenotypic plasticity than more shade-tolerant, later successional species (Ashton and Berlyn 1992). It has also been shown that the light saturation point of many temperate broadleaf tree species is about 20% to 30% of full sunlight (Chabot and Mooney 1985). Here we test two hypotheses: 1) morphological plasticity across an experimental light gradient ranging from 3% full sun to 67% full sun will be greater for the genus *Betula* than the genus *Acer*, and 2) the maximum degree of plasticity for genera and species will be expressed in the light treatment interval where photosynthetically active radiation (PAR) of 20% to 30% full sunlight occurs.

## Methods

Seedlings of two congeneric assemblages - grey birch (*Betula populifolia*), paper birch (*B. paperifera*), yellow birch (*B. alleghanensis*), striped maple (*Acer pennsylvanica*), red maple (*A. rubrum*) and sugar maple (*A. saccharum*) - were grown over their initial two growing seasons in a greenhouse at Yale-Myers Forest in Eastford, CT. Plants were grown in enclosures that represented four replications each of the following maximum PAR and Red:Far Red (R:FR) treatments respectively: 50 µmol $m^{-2}$ $sec^{-1}$, 0.46; 300 µmol $m^{-2}$ $sec^{-1}$, 0.97; 600 µmol $m^{-2}$ $sec^{-1}$, 1.15; 1200 µmol $m^{-2}$ $sec^{-1}$, 1.27 (Ashton and Berlyn, 1994). Soil moisture was held constant at field capacity. Destructive sampling was conducted at the end of the second growing season and the data was used to calculate the morphological traits presented in Table 1.

Analysis of variance was performed using PROC MIXED in SAS V8 to determine the effects of light and species, plus the interaction term of light * species on morphology. All *F* statistics, except light w/LWR ($P$ = .0563), were significant at the $P$ < .0001 level. Significance between trait values were determined using Tukey's HSD test at $P$ < .05. Plasticity indices, $\varphi$ = (maximum trait value – minimum trait value)/(maximum trait value), were calculated for each of three pairs of successive light treatments and once across the entire experimental gradient.

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# Results

## Morphological Traits

**Table 1.—Species mean values for morphological traits in four experimental light treatments.**

| PAR[1] | Grey Birch | Paper Birch | Yellow Birch | Striped Maple | Red Maple | Sugar Maple |
|---|---|---|---|---|---|---|
| 3% | | | | | | |
| SLA[2] | 442 (16) ab | 482 (20) ab | 521 (19) a | 448 (27) ab | 403 (21) b | 372 (67) b |
| LAR[3] | 95 (12) c | 152 (7) ab | 171 (8) a | 166 (19) a | 113 (11) bc | 71 (5) c |
| LWR[4] | 22 (2) b | 32 (1) a | 33 (1) a | 37 (3) a | 28 (2) ab | 21 (4) b |
| SWR[5] | 54 (2) a | 50 (1) ab | 46 (1) b | 36 (2) c | 30 (2) c | 34 (5) c |
| RWR[6] | 25 (2)b | 18 (1) b | 22 (1) b | 26 (2) b | 42 (3) a | 45 (5) a |
| 17% | | | | | | |
| SLA | 377 (17) ab | 381 (16) ab | 421 (20) a | 350 (17) ab | 369 (16) ab | 282 (13) b |
| LAR | 94 (5) ab | 103 (3) ab | 130 (9) a | 101 (7) ab | 116 (13) a | 58 (3) b |
| LWR | 24 (2) ab | 27 (1) ab | 31 (1) a | 29 (1) ab | 31 (2) a | 21 (1) b |
| SWR | 50 (3) a | 49 (2) a | 43 (1) ab | 36 (1) bc | 30 (2) c | 34 (2) c |
| RWR | 30 (2) bcd | 24 (1) d | 27 (1) cd | 35 (2) bc | 40 (3) ab | 45 (3) a |
| 33% | | | | | | |
| SLA | 247 (8) a | 228 (5) a | 264 (6) a | 215 (9) a | 242 (10) a | 204 (4) a |
| LAR | 57 (3) a | 62 (2) a | 84 (4) a | 62 (5) a | 65 (9) a | 40 (2) a |
| LWR | 23 (1) bc | 27 (1) abc | 32 (1) a | 29 (2) ab | 26 (2) abc | 20 (1) c |
| SWR | 37 (1) a | 36 (2) ab | 32 (1) abc | 32 (1) abc | 26 (1) c | 29 (2) bc |
| RWR | 40 (2) bc | 36 (2) c | 36 (2) c | 40 (2) bc | 48 (3) ab | 52 (2) a |
| 67% | | | | | | |
| SLA | 192 (3) a | 166 (5) a | 179 (6) a | 203 (8) a | 194 (11) a | 185 (5) a |
| LAR | 49 (2) a | 49 (2) a | 58 (3) a | 63 (6) a | 48 (3) a | 34 (1) a |
| LWR | 26 (1) ab | 29 (1) a | 32 (1) a | 31 (2) a | 25 (1) ab | 19 (1) b |
| SWR | 29 (1) a | 31 (2) a | 27 (1) a | 29 (1) a | 26 (1) a | 24 (1) a |
| RWR | 45 (2) bc | 40 (1) bc | 41 (1) bc | 40 (2) c | 49 (2) ab | 58 (2) a |

[1] Percent photosynthetically active radiation based on 1800 $\mu$mol m$^{-2}$ s$^{-1}$ as full sun

[2] specific leaf area (total fresh leaf area/total dry leaf mass, cm$^{2}$ g$^{-1}$)

[3] leaf area ratio (total fresh leaf area/total dry plant mass, cm$^{2}$ g$^{-1}$)

[4] leaf weight ratio (total dry leaf mass/total dry plant mass, %)

[5] stem weight ratio (total dry stem mass/total dry plant mass, %)

[6] root weight ratio (total dry root mass/total dry plant mass, %).

Means within a row followed by the same letter are not significantly different according to Tukey's HSD test ($P > 0.05$). Numbers in parenthesis are ± 1 standard error.

## Plasticity Indices

**Table 2.-Plasticity indices[1] for morphological traits across successive light treatments and entire treatment range.**

| PAR Intervals[2] | GB | PB | YB | TM | RM | SM | *BETULA*[8] | *ACER* |
|---|---|---|---|---|---|---|---|---|
| 3%/17% | | | | | | | | |
| SLA[3] | 0.15 | 0.21 | 0.19 | 0.22 | 0.08 | 0.24 | 0.18 a | 0.17 a |
| LAR[4] | 0.01 | 0.32 | 0.24 | 0.39 | 0.03 | 0.18 | 0.19 a | 0.20 a |
| LWR[5] | 0.08 | 0.16 | 0.06 | 0.22 | 0.10 | 0.00 | 0.10 a | 0.11 a |
| SWR[6] | 0.07 | 0.02 | 0.07 | 0.00 | 0.00 | 0.00 | 0.05 a | 0.00 b |
| RWR[7] | 0.17 | 0.25 | 0.19 | 0.26 | 0.05 | 0.00 | 0.20 a | 0.10 a |
| 17%/33% | | | | | | | | |
| SLA | 0.34 | 0.40 | 0.37 | 0.39 | 0.34 | 0.28 | 0.37 a | 0.34 a |
| LAR | 0.39 | 0.40 | 0.35 | 0.39 | 0.44 | 0.31 | 0.38 a | 0.38 a |
| LWR | 0.04 | 0.00 | 0.03 | 0.00 | 0.16 | 0.05 | 0.02 a | 0.07 a |
| SWR | 0.26 | 0.27 | 0.26 | 0.11 | 0.13 | 0.15 | 0.26 a | 0.13 b |
| RWR | 0.25 | 0.33 | 0.25 | 0.13 | 0.17 | 0.13 | 0.28 a | 0.14 b |
| 33%/67% | | | | | | | | |
| SLA | 0.22 | 0.27 | 0.32 | 0.06 | 0.20 | 0.09 | 0.27 a | 0.12 b |
| LAR | 0.14 | 0.21 | 0.31 | 0.02 | 0.26 | 0.15 | 0.22 a | 0.14 a |
| LWR | 0.12 | 0.07 | 0.00 | 0.06 | 0.04 | 0.05 | 0.06 a | 0.05 a |
| SWR | 0.22 | 0.14 | 0.16 | 0.09 | 0.00 | 0.17 | 0.17 a | 0.09 a |
| RWR | 0.11 | 0.10 | 0.12 | 0.00 | 0.02 | 0.10 | 0.11 a | 0.04 a |
| 3%/67% | | | | | | | | |
| SLA | 0.57 | 0.66 | 0.66 | 0.55 | 0.52 | 0.50 | 0.63 a | 0.52 b |
| LAR | 0.48 | 0.68 | 0.66 | 0.63 | 0.59 | 0.52 | 0.61 a | 0.58 a |
| LWR | 0.15 | 0.16 | 0.06 | 0.22 | 0.19 | 0.10 | 0.12 a | 0.17 a |
| SWR | 0.46 | 0.38 | 0.41 | 0.19 | 0.13 | 0.29 | 0.42 a | 0.20 b |
| RWR | 0.44 | 0.55 | 0.46 | 0.35 | 0.18 | 0.22 | 0.48 a | 0.25 b |

[1] Plasticity indices calculated as $\psi$ = (max trait value – min trait value)/(max trait value).

[2] Photosynthetically Active Radiation (based on 1800 $\mu$mol m$^{-2}$ s$^{-1}$ as full sun) intervals used to calculate between treatment plasticity indices.

[3] Specific leaf area (total leaf area/total dry leaf mass, cm$^{2}$ g$^{-1}$);

[4] leaf area ratio (total leaf area/total dry plant mass, cm$^{2}$ g$^{-1}$);

[5] leaf weight ratio (total dry leaf mass/total dry plant mass, %);

[6] stem weight ratio (total dry stem mass/total dry plant mass, %);

[7] root weight ratio (total dry root mass/total dry plant mass, %).

[8] Plasticity indices for Betula and Acer are calculated as means of the species within each genera. GB = grey birch; PB = paper birch; YB = yellow birch; TM = striped maple; RM = red maple; SM = sugar maple. Genera indices in rows followed by the same letter indicates no significant difference according to Tukey's HSD test (P > 0.05).

## Conclusions

At the genus level, *Betula* demonstrated a higher degree of plasticity than *Acer* for three out of the five morphological traits across the light range of 3% to 67% full sun, and two out of five traits at the 17% to 33% interval (Table 2). This indicates that *Betula* has greater flexibility in regulating carbon allocation to below ground storage organs (RWR) and above ground support and transport tissues (SWR), and a greater ability to optimize the structure and function of photosynthetic surfaces (SLA). These traits would point to a competitive advantage for *Betula* over *Acer* in rapidly changing light environments. This supports the known ecologies of the two genera but provides greater insight into some of the adaptations and mechanisms involved.

At both the genus and species levels, morphological trait plasticity was consistently greater at the 17% to 33% light interval than the 3% to 17% or the 33% to 67% intervals (Table 2.). The exception to this trend is LWR, which is discussed below. This would indicate that while phenotypic plasticity for these genera and species is expressed across the entire experimental light continuum, there are both lower and upper limits to plasticity that coincide with the stresses of extremely low and high light levels. Given this, it should be noted that, in general, species of the genus *Betula* maintained greater rates of plasticity at the highest light interval, which would indicate a greater niche breadth along the environmental axis of light.

Plasticity for LWR remained consistently low across all light treatments both at the genus and species level when compared to SLA and LAR (Table 2). This indicates that allocation of plant resources to overall leaf mass is a relatively fixed trait, and optimization of photosynthesis is provided by morphological, anatomical and physiological trait expression. Further research, such as correlating LAR to photosynthetic rates, will provide a greater understanding of the relationships between phenotypic plasticity and forest complexity in southern New England.

## Acknowledgments

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# *OPHIOSTOMA TETROPII* AS A DETECTION TOOL FOR THE BROWN SPRUCE LONGHORN BEETLE IN HALIFAX, NOVA SCOTIA

**K.J. Harrison†, G.A. Smith, J.E. Hurley and A.W. MacKay**

## Abstract

Since the discovery of the brown spruce longhorn beetle (BSLB), *Tetropium fuscum* (Fabr.) in a small area in the Halifax Regional Municipality in Nova Scotia in 1999, a species of *Ophiostoma* has been isolated repeatedly from BSLB-infested trees. This *Ophiostoma* was determined to be *Ophiostoma tetropii* Mathiesen (Jacobs and others, 2003). This European species was originally described from Norway spruce (*Picea abies* (L.) Karst.) infested with *Tetropium fuscum* and *Tetropium castaneum*. In Europe these insects are considered to be secondary, but in Halifax BSLB is attacking living and apparently healthy trees with green crowns and killing them (Smith and Humble, 2000). In Halifax, the native red spruce (*Picea rubens* Sarg.), white spruce (*P. glauca* (Moench) Voss) and black spruce (*P. mariana* (Mill.) BSP) as well as introduced Norway spruce, are attacked.

Since 2000, the Canadian Food Inspection Agency (CFIA) has designated BSLB as a pest of plant quarantine significance and has an on-going eradication program in place to detect and eradicate this insect from its first toehold in the forests of North America. Survey and detection of BSLB in the natural and urban forest is a serious challenge.

This presentation discusses the close association observed between *Ophiostoma tetropii* and BSLB in the infested spruce trees in Nova Scotia. We have found that *Ophiostoma tetropii* can be readily isolated on selective culture media and identified in about one month. Successful insect rearing for BSLB can take a minimum of 12-14 weeks for overwintered wood bolts or 24-28 weeks for wood bolt samples collected in late summer when the insect is in an early larval stage. When low populations of BSLB exist in stands where the majority of spruce trees are infested with native bark beetles, it is very difficult to detect the BSLB. The presence of *Ophiostoma tetropii* is a strong indicator that BSLB is or was present in the stand, so the use of the fungal associate as a detection tool offers timely answers to focus the eradication effort.

## Acknowledgments

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# PARTIAL CUTTING IMPACTS ON MACROINVERTEBRATES IN EPHEMERAL STREAMS IN SOUTHERN NY

**E.J. Paashaus[†], R.D. Briggs, and N.H. Ringler**

## Abstract

Macroinvertebrate sampling was used to biomonitor ephemeral stream water quality in partially harvested (Feb 2002) and reference watersheds in the Catskill Mt. Region of southern NY. Streams were sampled with a Surber sampler in May and June of 2001 (pre-harvest) and 2002 (post-harvest). Macroinvertebrates were hand sorted in the field, placed in 70% alcohol, and returned to the lab for identification to genus. The macroinvertebrates collected were distributed across 7 orders and 26 families. Faunal community structure varied greatly between years within the reference sites. A variety of indices were computed from the sample data: index of biotic integrity, Hilsenhoff improved biotic index, family level biotic index, North Carolina biotic index, functional feeding groups, and Shannon H and Simpson D diversity indices. These indices provided no evidence that a partial harvest negatively impacted water quality. Diversity may have been reduced following harvesting, but the high variability precluded a definitive conclusion.

## Introduction

Benthic macroinvertebrates are being utilized as a tool to assess surface water quality (Bailey et al. 2001). Ease of collection and identification are important advantages relative to other organisms (i.e. algae). The combination of limited mobility, short life spans, and differential tolerance to a variety of pollutants makes macroinvertebrates potentially attractive as indicators of local, recent conditions (Davis et al. 2001). Most of the macroinvertebrate sampling has been done in perennial streams. Caruso (2002) is one of the few to examine benthic macroinvertebrate communities during extreme low flow conditions resulting from severe drought. He found reduced number of sensitive taxa and reduced diversity, although the magnitude of the differences was small and did not differ statistically from the pre-drought period. The purpose of this study was to examine the effects of a partial cut on aquatic macroinvertebrate populations in small ephemeral streams in southern New York using a variety of biotic indices.

## Methods

Two adjacent paired watersheds were selected at Frost Valley located along the west branch of the Neversink River in the Catskill Mountains of Ulster County, New York (41°59’ N; 74°31’ W). Sixty percent of the basal area was harvested in a heavy improvement thinning from the lower 6 ha portion of 10 ha Frost Valley site A during February – May 2002. Adjacent site G served as an untreated reference. An untreated reference site was located at Ninham. During 2002, we added one additional reference site at Ward Pound Ridge.

Macroinvertebrates were sampled at each of the 4 sites: May – June 2001, and May – June 2002, with the exception of Ward Pound Ridge which was not sampled in 2001. Sampling was prevented in July and August by lack of water. Streams were partitioned into either erosional (sediment being eroded from stream bed) or depositional (sediment being deposited into streambed) sections. Each stream section was assigned a number and 6 erosional and 6 depositional sections were randomly selected at each sampling date. A Surber sampler (30.5 cm x 30.5 cm with mesh size 0.363 mm) was placed in the substrate. Sediment was disturbed to a depth of 10 cm forcing dislodged material into the water column passing through the net. Material was washed into a plastic tray and hand sorted in the field under 5-10x magnification. Macroinvertebrates were preserved in 70% ethyl

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alcohol and returned to the lab for identification to genus. Macroinvertebrate data were utilized to compute the following indices: IBI, index of biotic integrity (Fore et al. 1994); BI, Hilsenhoff improved biotic index (Hilsenhoff 1987); FBI, family level biotic index (Hilsenhoff 1988); NCBI, North Carolina biotic index (Lenat 1993); FFG, functional feeding groups (Merritt and Cummins 1996); and Shannon H and Simpson D diversity indices (Magurran 1998).

## Results and Discussion

A total of 477 macroinvertebrates distributed across 7 orders and 26 families were collected from the sampled streams in 2002 (Table 1). The streams dried up in July and August, restricting sampling to May and June of each year. There was considerable variation in faunal communities between years even within the reference sites.

**Table 1.- Summary of macroinvertebrates collected from sample streams during May-August 2002. Numbers in parentheses indicate percentage of organisms in dominant family.**

| | Frost Valley A | Frost Valley B | Ninham | Ward Pound Ridge |
|---|---|---|---|---|
| Number | 225 | 58 | 69 | 125 |
| Dominant | *Simuliidae* (72%) | *Chironomidae* (29%) | *Isonychiidae* (20%) | *Isonychiidae* (22%) |
| Taxa | *Prosimulium* | *Chironomus* | *Isonchia* | *Isonchia* |

Comparison of the indices between ephemeral streams in treated and harvested watersheds indicated no detectable effects of the harvest on macroinvertebrate communities (Table 2). All sampled streams, even in the harvest treatment, were classified as “fair” in 2001 using the IBI. The BI and FBI indices indicated a slight reduction in quality from 2001 to 2002 for Frost Valley streams in both harvested and reference watersheds while the BI for Ninham increased from “good” to “excellent”. These two indices were designed to detect organic pollution which causes reduced dissolved oxygen levels. All streams were rated “excellent” by the NCBI. Although the FSBI exhibited the greatest change between harvested and reference streams at Frost Valley, the magnitude of the difference between years for Ninham was opposite in sign compared to the Frost Valley reference watershed. Consequently, the results are inconclusive. The poor performance of this index is partially due to the fact that only 3-4% of the organisms collected could be assigned tolerance values.

There were no consistent changes in the proportion of functional feeding groups attributed to harvesting. In theory, disturbances can have large impacts on invertebrate community structure. Variation in FFG between years was high for both treated and reference watersheds at Frost Valley.

Simpson and Shannon diversity indices both decreased from 2001 to 2002 in the harvested watershed and increased in the untreated Frost Valley watershed; there was very little change at Ninham.

## Conclusions

Biomonitoring of macroinvertebrates in ephemeral streams in southern NY over a 2-year period provided no evidence that a partial harvest negatively impacted water quality. Harvesting may have reduced diversity the first year following harvest, however, the high degree of variability for these ephemeral streams limits the strength of this observation. In order to understand more fully the potential utility of macroinvertebrate monitoring for ephemeral stream water quality, the number of streams and the duration of the monitoring period must be increased.

**Table 2.- Summary of indices computed from macroinvertebrate data[1].**

| Index[2] | FV Harvested |  | FV Reference |  | Ninham |  | WPR |
|---|---|---|---|---|---|---|---|
|  | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2002 |
| IBI | 21<br>Fair | 19<br>Fair | 16<br>Fair | 27<br>Good | 20<br>Fair | 27<br>Good | 30<br>Good |
| BI | 4.32<br>V Good | 5.05<br>Good | 3.4<br>Excel | 4.6<br>Good | 4.8<br>Good | 3.48<br>Excel | 2.3<br>Excel |
| FBI | 4.5<br>Good | 5.02<br>Fair | 3.82<br>V Good | 4.48<br>Good | 3.09<br>Excel | 3.03<br>Excel | 1.97<br>Excel |
| NCBI | 2.383<br>Excel | 3.011<br>Excel | 2.906<br>Excel | 3.936<br>Excel | 3.9<br>Excel | 3.297<br>Excel | 4.036<br>Excel |
| FSBI | 3.08 | 4.10 | 4.29 | 3.60 | 2.68 | 3.25 | 4.20 |
| Diff = 2002-2001 | 1.02 |  | -0.79 |  | 0.57 |  | NC |
| FFG[3] |  |  |  |  |  |  |  |
| Predators % | 28 | 2 | 4 | 31 |  |  |  |
| Collectors % | 36 | 74 | 6 | 45 | NC | NC | NC |
| Shredders % | 36 | 24 | 90 | 24 |  |  |  |
| Simpson D | 5.95 | 1.88 | 2.31 | 5.55 | 8.29 | 7.3 | 9.35 |
| Shannon H | 0.85 | 0.55 | 0.57 | 0.88 | 1.03 | 0.95 | 1.1 |

[1] FV indicates Frost Valley. WPR indicates Ward Pound Ridge, NC = not computed. Index abbreviations detailed in Methods.

[2] Interpretation of index listed below raw score (Excel is short for excellent).

[3] Functional feeding groups listed as percentage of organisms identified as predators, collectors, and shredders.

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# FOUR DECADES OF COOPERATIVE FORESTRY RESEARCH AT THE UNIVERSITY OF MAINE

**Robert G. Wagner† and Daniel J. McConville**

Maine's large forest land owners have long recognized the need to support a strong research effort as part of their managing Maine's forests. In 1975, a small group of visionary forest industry leaders and representatives of the University of Maine formed the Cooperative Forestry Research Unit (CFRU). It is now one of the oldest industry/university forest research cooperatives in the United States, and continues to serve as a model of joint leadership and cooperation between Maine's largest industry and the University of Maine.

The CFRU is composed of about 27 private and public forest land management organizations from across the state that guide and support research on key forest management issues facing Maine's forest landowners and managers (www.umaine.edu/cfru/). The mission of the CFRU is to *"conduct applied scientific research that contributes to the sustainable management of Maine's forests for desired products, services, and conditions."* The CFRU has been generously supported for 28 years through the voluntary financial and in-kind contributions of its members.

During that time, the CFRU has researched and solved a number of crucial issues facing Maine's forest managers. In recent years, the CFRU also has become the primary research and development effort supporting third-party forest certification in the state. CFRU research has had two primary objectives: 1) develop information and tools to improve the efficiency and productivity of forest management and 2) provide science-based information about the ecological effects of forestry practices.

Research focusing on the ecological effects of forestry practices has allowed the CFRU to provide scientific information that has been instrumental in helping the forest industry meet the requirements of certification by the Sustainable Forestry Initiative and Forest Stewardship Council. In addition, this research has provided key information for policy makers addressing a number of important forestry issues in Maine and elsewhere. Key CFRU accomplishments include:

1. Identifying the habitat requirements for American marten and increasing our understanding about how forest fragmentation influences this important habitat
2. Documenting the effect that herbicides have on the habitat of moose and other mammals
3. Documenting the influence that whole-tree harvesting has on nutrient losses from forest sites (The Weymouth Point study)
4. Conducting critical analyses of the state's wood supply that have influenced management decisions and financial investments in the Maine woods
5. Introducing a variety of new vegetation management methods and tools that have increased reforestation success on harvested lands
6. Introducing a site classification system for spruce-fir (Briggs system) and hardwood sites that have improved land stratification and silviculture across the state
7. Providing key recommendations for managing stands that were damaged by the spruce budworm during the 1970s and 80s
8. Documenting that nitrogen fertilizer does not increase the growth of spruce-fir stands unless they have been previously thinned
9. Quantifying how silvicultural practices influence wood quality in future forest stands

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10. Providing insight into how to better manage beech bark disease
11. Demonstrated that the application of wood ash and paper mill sludge to the forest does not increase forest growth

Current CFRU research continues this tradition with a focus on improving silviculture in the Maine forest (commercial thinning, hardwood management, yield gains from young stand management, growth and yield, wood supply) and improving our understanding about the influence of forest management on wildlife habitat (PCT influences on hare, lynx habitat preferences, marten habitat supply) and conservation of biodiversity (patch retention, buffer strips and aquatic protection, biodiversity indices).

In addition to the above research accomplishments, and perhaps even more importantly, CFRU-sponsored research on The University of Maine campus has provided scores of undergraduate students, graduate students, and faculty in forestry and wildlife with the opportunity to learn about and help solve some of the most important problems facing forest managers in the state. This investment has provided a wealth of expertise that has been drawn upon by forestry organizations, government agencies, and the public when information and advice was needed about key sustainable forestry issues. The CFRU has had a positive and lasting influence on the forestry culture at The University of Maine by providing a direct link between the university and the people managing Maine's forest land. As a result, the CFRU has been identified as one of top six accomplishments being celebrated during the 100th anniversary of forestry program at the University of Maine (2003-2007).

# MAINE'S COMMERCIAL THINNING RESEARCH NETWORK

## Robert G. Wagner†, Robert S. Seymour, and Daniel J. McConville

Maine's Commercial Thinning Research Network was established in 2000 to develop a better understanding about stand responses to commercial thinning in the state's forests. Initial efforts by the network are divided into two phases. Phase I developed a set of interim guidelines for commercial thinning through the development of a software product called ThinME. Phase II, representing most of the effort, has involved establishing a statewide network of research sites to address specific questions about commercial thinning. Data from Phase II will help further refine the thinning software developed in Phase I, improve regional growth and yield models related to thinning responses, and address other silvicultural questions of interest. The plot network is currently focused on answering two key questions about commercial thinning in spruce-fir stands across the state: (1) For natural spruce-fir stands that have not received precommercial thinning (PCT), what is the influence of (a) method of commercial thinning and (b) residual density on subsequent stand response? (2) For natural spruce-fir stands that have received previous PCT, what is the influence of (a) timing of first commercial thinning entry and (b) residual density on subsequent stand response?

Twelve study sites have been established across the state of Maine. Six sites have previously received PCT and range in age from 25 to 40 years old. The other six sites have never received PCT and range from 40 to 70 years old. At each site, seven 0.37-ha (61 m x 61 m) treatment plots have been established. Commercial thinning treatments in stands that have not received PCT include a factorial combination of thinning method (low, crown, or dominant) and level of relative density reduction (33% or 50%). Commercial thinning treatments in stands that have received PCT include a factorial combination of timing of first commercial thinning (now, delay 5 yrs, or delay 10 yrs) and level of relative density reduction (33% or 50%). The thinning treatments, which used single-grip harvesters and forwarder trails spaced 30.5 m apart, were applied from fall 2000 through fall 2002. Four 0.02-ha (15.2 m x 13.3 m) measurement plots were placed at the center of each treatment plot. All plots have been measured before and after thinning. Regular post-treatment measurements are being collected from permanent tagged trees. Measurements include species, DBH, tree location, total height, and height to live crown.

Projected stand responses of the study plots have been recently developed from pre- and post-thinning data using projections from the USFS Forest Vegetation Simulator (NE TWIGS variant). These projections provide quantitative hypotheses about future growth of the residual stands and provides an opportunity to examine how existing growth and yield models, which have not been developed with any commercial thinning response data, handle projections for a wide variety of thinning treatments.

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# LEAF AREA AS A GROWTH PREDICTOR FOR RED SPRUCE AND BALSAM FIR IN MANAGED STANDS IN MAINE

**S. R. Meyer**[†]

## Abstract

Forest stand structure is a function of many natural, ecological and anthropogenic processes. Currently, most growth models are empirically based on size attributes in stands. These model types are based on the assumption that wood growth is a function of the amount of wood present. Using leaf area as a determinant of density and structure applies physiological and ecological processes to stand growth. Models based on leaf area may reflect growth dynamics (i.e. differentiation) within the stand, while others assume all trees of similar sizes to have the same growth rate. The well-established leaf area-sapwood area (LA:SA) relationship may be used to estimate biologically-significant growth model parameters. The objectives of this study are 1) to validate the relationship between the leaf area and the sapwood area for *Abies balsamea* (L.) Miller and *Picea rubens* (Sarg.) in Maine; 2) to quantify a growth modifier for individual trees; and 3) to better model the growth of managed stands based on crown dynamics.

Data from destructive sampling during the summer of 2003 was used to estimate tree-level specific leaf area (SLA) based on the LA:SA relationship. This instance of SLA estimation is comparable to that of Gilmore et al. (1996) and to a crown length model (Valentine et al. 1994) to evaluate its effectiveness for estimating leaf area. Analysis of variance (ANOVA) was used to evaluate the model's performance across several variables, including site, age, and crown position. Inter-model comparisons were evaluated following the methods of Kenefic and Seymour (1999) and Gilmore et al. (1996).

By using growth increment cores taken at all sites during the 2003 field season, this study attempted to reconstruct past leaf area based on constructed LA:SA equations. Stand growth was projected 5 years with Forest Vegetation Simulator (FVS - Northeast variant – U.S. Forest Service, Growth Management Service Center) using the reconstructed growth data. FVS results were compared to the actual growth change observed from the radial increment record. Volume increment (VINC) to projected leaf area relationships were compared across sites with ANOVA. Ratios of prior VINC to current VINC were compared to investigate its use as a growth potential modifier. Several parameters were tested in order to construct a growth potential modifier that most improves the FVS Northeast variant growth model performance.

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**Key words:** forestry; sustainability; tree growth; New England; vegetation dynamics; silviculture; forest health.

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