The Vermont Forest Ecosystem Management Demonstration Project

Principal Investigator:
William S. Keeton

University of Vermont, Rubenstein School of Environment and Natural Resources
343 Aiken Center, Burlington, VT 05405
william.keeton@uvm.edu

Co-Principle Investigators:
Austin R. Troy
Allan M. Strong
Donald R. Tobi
Margaret Skinner

Completion date: 9/30/08

This project has experimentally tested the ecological and economic effects and tradeoffs involved in a range of modified, low intensity uneven-aged silvicultural treatments in northern hardwood forests. Modified uneven-aged systems can be employed to promote development of late-successional structural characteristics and certain elements of associated biological diversity. These systems are economically viable under the right market and site conditions. Applications are relevant to a variety of sustainable forest management scenarios.

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service. <http://www.nsrcforest.org/>

Project Summary

The use of low-intensity, disturbance- or structure-based silvicultural systems is often proposed for the maintenance of biological diversity and ecosystem functioning across managed forest landscapes. In the northern hardwood region of the eastern United States and Canada this includes managing for late-successional structure, which is vastly under-represented relative to pre-European settlement conditions. One possibility is to modify uneven-aged silvicultural practices to more closely approximate fine-scale natural disturbance effects. The as yet untested hypothesis is that these approaches would result in accelerated rates of late-successional structural development and related ecological functions, while also providing economic returns from low-intensity timber harvests. The Vermont Forest Ecosystem Management Demonstration Project is testing this hypothesis using a variant of uneven-aged forestry, termed "Structural Complexity Enhancement (SCE)," that promotes old-growth structural characteristics. This approach is compared against two conventional uneven-aged systems (single-tree selection and group-selection) modified to enhance post-harvest structural retention. The study is replicated at two mature, northern hardwood forests in Vermont. Manipulations and controls were applied to 2 ha units. The uneven-aged treatments were replicated twice; the SCE treatment and controls were each replicated four times. Structural objectives in SCE include multi-layered canopies, elevated large snag and downed log densities, variable horizontal density, and re-allocation of basal area to larger diameter classes. Data on operational expenses and revenue, sorted by treatment unit and product grade, were collected during and after logging operations, as was information on market conditions. Forest structure and biodiversity (plants, salamanders, birds, and carabid beetles) data have been collected over two years pretreatment and four years post-treatment. Fifty-year simulations of stand development were run using the northeastern variant of the Forest Vegetation Simulator, comparing alternate treatments and no treatment scenarios. There will be significant differences in stand development based on the simulation modeling. Late-successional structural and compositional characteristics, including aboveground biomass (and related carbon storage capacity), will develop to a greater degree under SCE. Large tree (>50 cm dbh) recruitment will be impaired under the conventional treatments, whereas rates of large tree development will be significantly accelerated under SCE. Elements of biological diversity associated with late-successional forests, including sensitive and interior dwelling herbaceous plants and birds, terrestrial salamanders, and certain groups of carabid beetles, were least impacted by SCE; in some cases populations responded positively to habitat conditions created by this and the conventional treatments. Siviculturists have the flexibility to manage for wide range of structural characteristics and associated ecosystem functions using unconventional silvicultural approaches. These will not maximize revenue compared to more intensive harvesting practices. However, if site quality and market conditions are conducive, they will provide a moderate level of economic return. Applications range from old-growth and riparian forest

Background and Justification

Introduction

The Vermont Forest Ecosystem Management Demonstration Project (FEMDP) has the goal of bringing together researchers from diverse fields in an experimental test of forest management effects on northern hardwood ecosystems. Sustainable forestry practices across managed forest landscapes contribute to the maintenance of biological diversity and ecosystem functioning. "Structure-" or "natural disturbance-based" silvicultural approaches provide alternatives for this kind of management. Structure-based forestry focuses on the architecture of forest ecosystems at both stand-level and landscape-level spatial scales. Disturbance-based silviculture attempts to approximate the range of structural and compositional conditions associated with natural disturbance regimes. These approaches share the operational objective of managing for currently under-represented forest structures and age classes.

In the northern hardwood region of eastern North America a structure or disturbance-based approach would include managing for late-successional structure, which is vastly under-represented relative to pre-European settlement conditions. An untested hypothesis is that silviculatural practices can accelerate rates of late-successional forest stand development, promote desired structural characteristics, and enhance associated ecosystem functions more than conventional systems. We have tested this hypothesis using an approach, termed "Structural Complexity Enhancement (SCE), that promotes old-growth characteristics while also providing opportunities for low-intensity timber harvest. SCE was compared against two conventional uneven-aged systems advocated regionally for sustainable forestry. Conventional uneven-aged prescriptions employed in this study were modified to increase post-harvest structural retention. In addition, group-selection treatments were modified to approximate the average canopy opening size associated with fine-scale natural disturbance events in the northeastern United States based on previous research.

Alternative Silvicultural Approaches

Interest in structure-based silviculture has evolved from studies of old-growth northern hardwood and mixed hardwood-conifer forests. These have demonstrated the ecological significance of specific structural elements associated with late-successional and old-growth forests. Availability of these structures can be highly limited in forests managed under conventional even and uneven-aged systems. Managing for late-successional forests has the potential to enhance ecosystem services associated with structural complexity, such as a subset of wildlife habitats, carbon storage, and riparian functions. As a result, managing for old-growth structural characteristics, either in part or in full, is a proposed alternative silvicultural approach. While there has been much discussion of old-growth forest restoration in the theoretical literature, there have been few experimental studies of relevant silvicultural methods for northern hardwood forests. Thus, it remains uncertain whether active restoration offers advantages over passive (or non-manipulative) restoration as means for recovering old-growth forest conditions. Our experimental test of SCE addressed this uncertainty.

The objectives of SCE include vertically differentiated canopies, elevated large dead tree and downed coarse woody debris (CWD) densities, variable horizontal density (including small gaps), and re-allocation of basal area to larger diameter classes. The later objective is achieved, in part, using an unconventional marking guide based on a rotated sigmoid target diameter distribution. Rotated sigmoid diameter distributions have been widely discussed in the theoretical literature, but their silvicultural utility has not been field tested. Sigmoidal form is one of several possible distributions in eastern U.S. old-growth forests. These vary with disturbance history, species composition, and competitive dynamics. The distribution offers advantages for late-successional structural management because it allocates more growing space and basal area to larger trees. We predicted that the rotated sigmoid distribution is sustainable in terms of recruitment, growth, and yield. If so, it would suggest that foresters have greater flexibility in managing stand structure, biodiversity, and other ecosystem functions in the northern forest region than previously recognized.

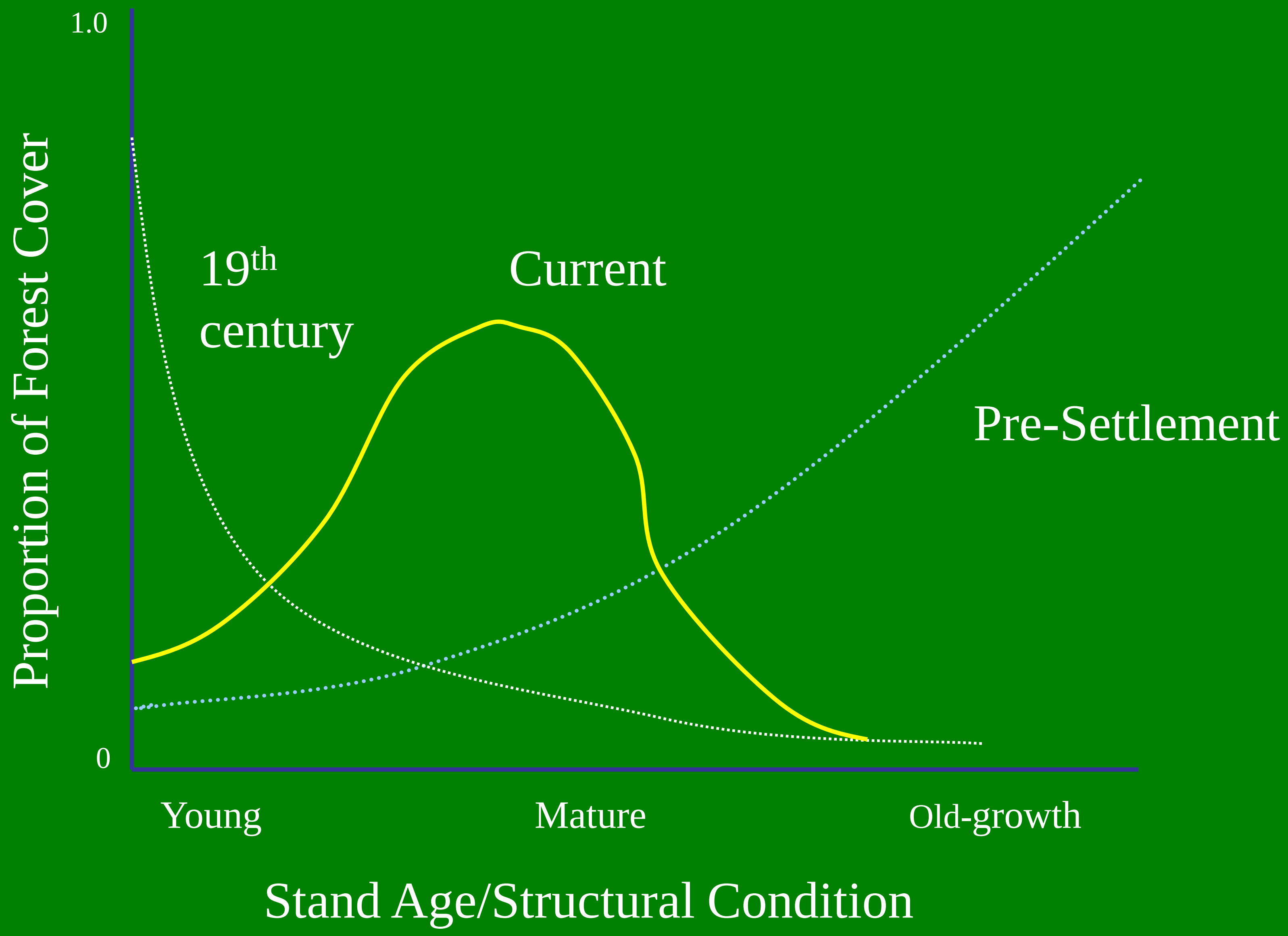
Biodiversity Indicators

Our research has focused on a number of taxa selected as useful indicators of biodiversity responses to silvicultural treatment. Taxa were selected based on three criteria: 1) ecological significance (e.g. effects on key processes); 2) habitat requirements related to aspects of forest structure and within-stand environmental conditions likely to be modified by the experiment; and 3) population responsiveness at scales detectable by our sampling methodology. The later criterion applies to all of our indicator taxa except birds, for which we employed a different approach to assess treatment effects. Biodiversity indicators monitoring by the FEMDP include vegetation (overstory and understory; vascular and non-vascular), birds, amphibians, and select soil invertebrates. Methods and results for the biodiversity component of this study are reported in Keeton et al. (in preparation), Smith et al. (in press), and McKenny et al. (2006). Please see the "list of products" for citations.

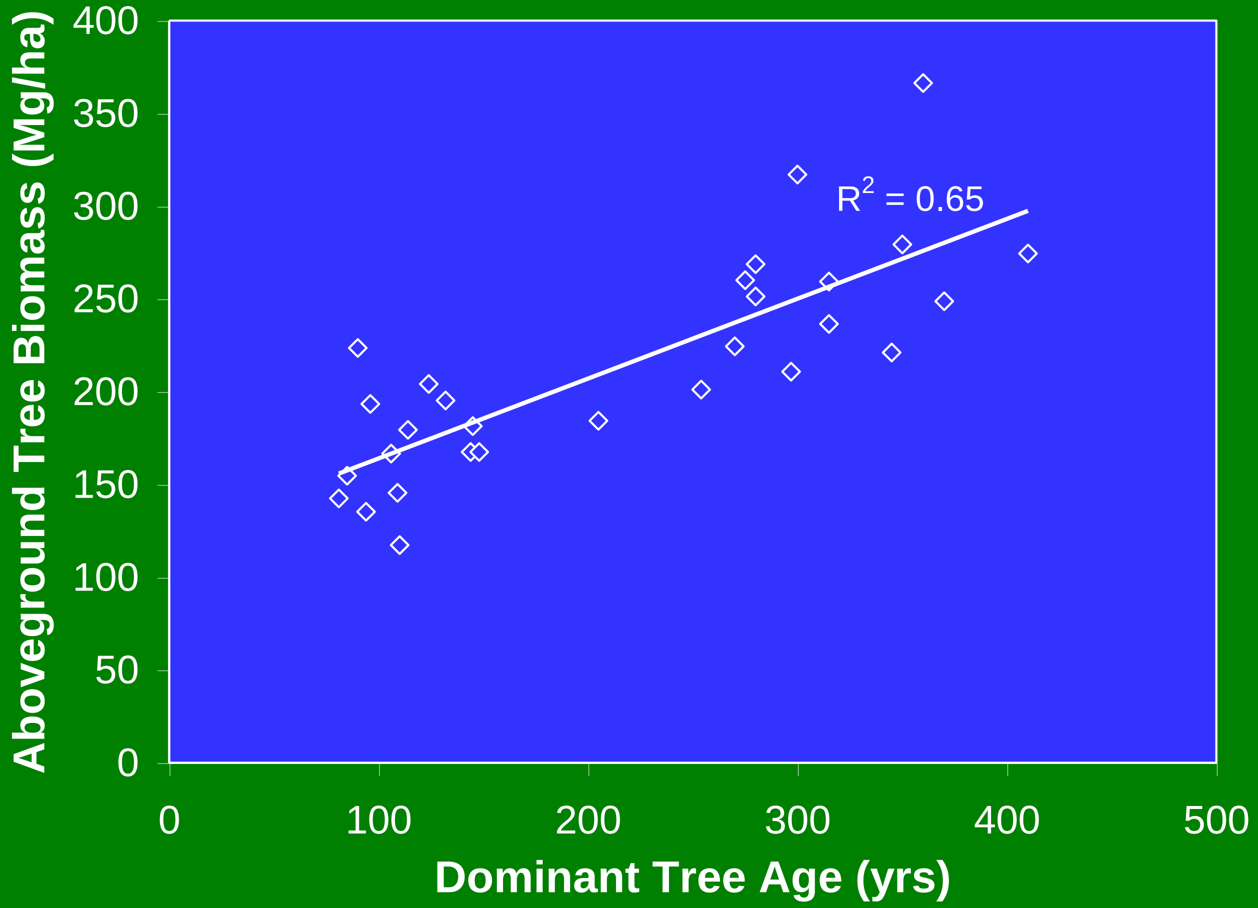
Economic Tradeoffs

Our research is evaluating the economic tradeoffs among the structure-based systems tested. The objective is to determine the stand (timber volume and quality), site (accessibility and cost of harvesting operations) and market conditions necessary for structure-based systems to be economically viable and profitable. The economics of systems that promote structural complexity are poorly understood. Previous research has shown that revenue and product type vary widely with even small modifications to uneven-aged prescriptions (Niess and Strong 1992, Buongiorno et al. 1994). For alternative silvicultural approaches to have appeal for landowners and forest managers, their operational and economic feasibility must be demonstrated. We are evaluating economic feasibility from a present value framework, factoring in the price uncertainty stemming from the output of diverse products. This analysis will allow us to address a number of research questions. For instance, what are the economic tradeoffs involved with varying intensities of timber removal versus habitat enhancement? What is the economic viability of alternative silvicultural models under different scales of production? What is the level of economic uncertainty of these systems? How sensitive are returns to market prices of different forest products? And finally, what factors beyond stumpage volume, price, and interest rates affect economic feasibility and risk?

Changes in Age-Class Distributions



Why manage for old-growth structure: Carbon Storage



Keeton et al. 2007. Ecological Applications

Why manage for old-growth structure: Riparian Functions

Keeton et al. 2007. Ecological Applications

Methods

Experimental Design and Data Collection

The study is replicated at two mature, multi-aged, northern hardwood forests in the northern Green Mountain Range in Vermont, U.S.A. There are three experimental manipulations. The first two are conventional uneven-aged systems (single-tree selection and group-selection) modified to increase post-harvest structural retention and to represent best available practices. Prescriptions are based on a target residual basal area of 18.4 m2/ha, max. diameter of 60 cm, and q-factor of 1.3. Group-selection cutting patches are each approximately 0.05 ha in size. The third treatment is Structural Complexity Enhancement (SCE). The marking guide is based on a rotated sigmoid target diameter distribution applied as a non-constant q-factor. The marking guide is also derived from a target basal area (34 m2/ha.) and maximum diameter at breast height (90 cm) indicative of old-growth structure. Accelerated growth in larger trees is promoted through full (4 or 3-sided) and partial (2-sided) crown release. Prescriptions for enhancing dead tree and downed woody debris volume and density are based on pre-harvest CWD volume and literature-derived targets. On one SCE unit at each of the two study areas, downed logs are created by pulling trees over, rather than felling, to create pits and exposed root wads.

Each of the first two treatments (uneven-aged) is replicated twice; the third (SCE) is replicated four times. Two un-manipulated control units are located at each of the two study areas. Treatment units are 2 ha in size and separated by 50 meter (min.) buffers. Treatments were randomly assigned. Experimental manipulations (i.e. logging) were conducted on frozen ground in winter 2003. Sample data were collected from five 0.1 ha permanent sampling plots randomly established in each treatment unit. Forest structure data, including leaf area index (LAI), detailed measurements of individual trees, and coarse woody debris (CWD) densities and volumes, have been collected over two years pretreatment and four years post-treatment. Plots were stem-mapped using an integrated laser range finder and digital electronic compass.

To track operational expenses loggers were required to file daily worksheets. These recorded hours worked, equipment use and repairs, number and type of loads, and work conditions. Harvested logs were separated into four product grades: saw logs, veneer logs, firewood, and chip wood. Logs were then segregated by treatment, transported, and tracked independently by unit through to scaling (valuation) at the processing mill. In this way harvest volumes and revenue could be tracked by treatment, species, size class, and grade or product.

Data Analysis

Forest sample data were used as inputs for 3-dimensional modeling in the Stand Visualization System (SVS). The Northeast Decision Model was used to generate stand structure metrics based on pre and post-harvest sample data. Structural metrics were analyzed using a before/after/control/impact statistical approach. For this purpose we used Tukey-tests, Analysis of Variance, and post-hoc Bonferroni or Least Significant Difference multiple comparisons. Fifty-year simulations of stand development were run using two models: the northeastern variant of the Forest Vegetation Simulator (FVS) and NE-TWIGS. The FVS modeling structure is based on NE-TWIGS, which is an individual tree-based, distance-independent stand growth simulator. However, mortality and large-tree growth functions operate slightly differently in NE-FVS and calculations are made every ten years, rather on the annual time step employed in NE-TWIGS. We ran simulations for individual experimental units and for both “no-treatment” (pre-harvest data) and “treatment” (post-harvest data) scenarios. Cumulative basal area increment (CBAI) was calculated for each simulation run at 5 year intervals. Projections were normalized on a unit by unit basis by calculating the differences between “no-treatment” and “treatment” scenarios at each time step. The Kolmogorov-Smirnov two-sample goodness of fit test was used to test for differences between treatment groups along mean projected time series.

Economic data were entered into a Microsoft Access relational database. The series of linked tables includes hours worked by activity and treatment unit; receipts and quantity by product grade, type and load; number, size and destination of loads by treatment unit; costs per hour by equipment and personnel class, and added expenses. Operational expense and revenue data were used to quantify costs and net profits under each treatment for three cost scenarios designated as “non-profit,” “semi-profit,” and “for-profit.” The scenarios reflected the extent to which expenses not directly linked to harvesting, such as timber marking, would be accounted for as costs. Linear regression analysis was used to model relationships between receipts and pre-harvest timber volume. Revenue by treatment was also evaluated as a ratio relative to labor hours, since this was the greatest operational expense by at least one order of magnitude.

Structural Complexity Enhancement (SCE)

Structural Objective	**Silvicultural Technique**
Multi-layered canopy	• Single tree selection using a target diameter distribution • Release advanced regeneration • Establish new cohort
Elevated large snag densities	• Girdling of selected medium to large sized, low vigor trees
Elevated downed woody debris densities and volume	• Felling and leaving, or • Pulling over and leaving
Variable horizontal density	• Harvest trees clustered around "release trees" • Variable density marking
Re-allocation of basal area to larger diameter classes	• Rotated sigmoid diameter distribution • High target basal area • Maximum target tree size set at 90 cm dbh
Accelerated growth in largest trees	• Full and partial crown release of largest, healthiest trees

Treatment Comparison

1. Single-Tree Selection

   → BDq modified to enhance post-harvest structural retention

2. Group Selection

   → BDq modified to enhance post-harvest structural retention

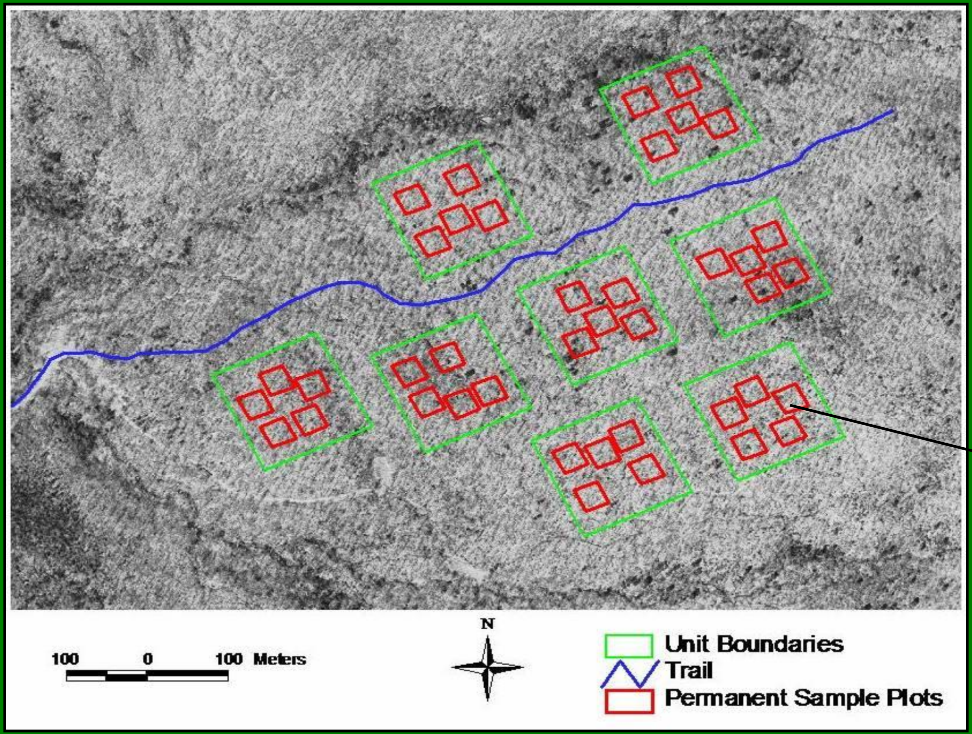
   → Mimic opening sizes (0.05 ha) created by fine-scale natural disturbances

3. Structural Complexity Enhancement:

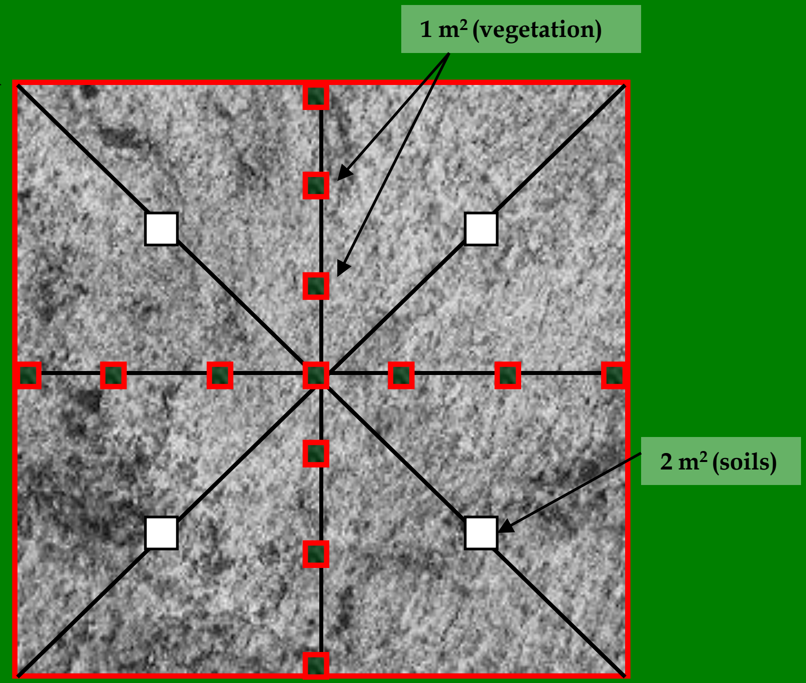
   → Promotes late-successional/old-growth characteristics

Experimental Design

Mt. Mansfield State Forest



- 2 ha treatment units
- 0.1 ha permanent plots (overstory structure)



- 13 vegetation quadrats (1 m^2)
- Transects: CWD and seedlings
- 4 soil subplots (2 m^2)

RESULTS

Results: Stand structure and projected development

Residual stand structure

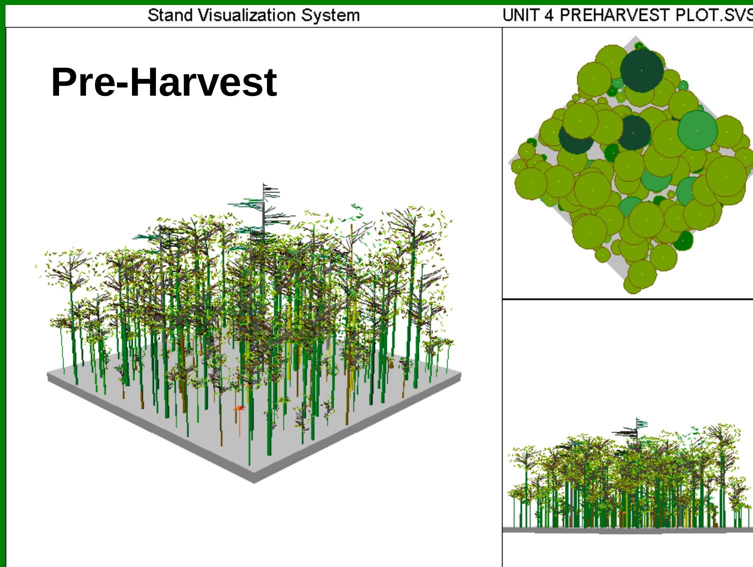
Post-harvest basal area, canopy closure, and LAI were significantly ($\alpha = 0.05$) higher under SCE compared to conventional treatments. Conventional treatments resulted in significantly lower aboveground biomass ($P = 0.014$), total basal area ($P = 0.003$), relative density ($P = 0.002$), and stem density ($P = 0.008$) in comparison to control units. SCE did not result in statistically significant contrasts with controls. Canopy closure was most variable across group-selection units. There were significant differences ($P < 0.001$) in LAI responses among treatments. Single-tree and group selection cuts reduced LAI by 19.8 and 29.9% respectively. LAI reductions were lowest in SCE units (9.4%), indicating high retention of vertical complexity. LAI was significantly more spatially variable for both SCE ($P = 0.031$) and group-selection ($P = 0.010$) compared to single tree selection; within-treatment variance was not significantly different between SCE and group-selection units ($P = 0.296$). These results are indicative of the high degree of horizontal structural variability expected for both group-selection and SCE, achieved in the later through variable density marking and clustered harvesting around crown-release trees. SCE shifted residual diameter distributions to a form statistically indistinguishable ($\alpha = 0.05$) from the target rotated sigmoid form.

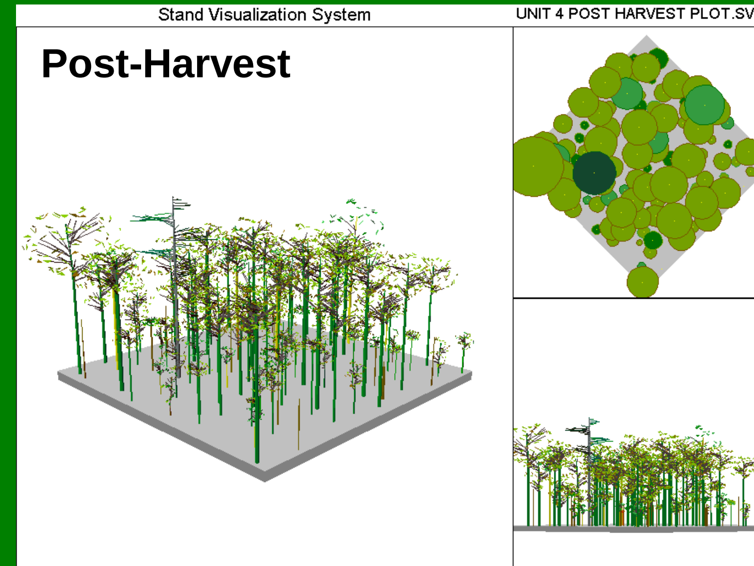
Projected stand development

Stand development projections suggest that total basal area under SCE will, on average, approach 34 m2/ha after 50 years of development (figure 2). This is 24 % (or 8 m2/ha) higher than the mean predicted for the conventional uneven-aged units. Projected basal area for SCE also exceeds the mean predicted for control units by 13% (or 4.5 m2/ha). Conventional units were projected to have basal areas still 12 % (or 3.6 m2/ha) below the control units after 50 years of development. However, the difference among treatments is largely an artifact of the higher residual basal area left by SCE. The projections showed no significant differences in absolute growth rates between treatment scenarios. Both SCE ($P < 0.05$) and conventional treatments ($P < 0.01$) are projected to significantly accelerate tree growth rates above that expected with no treatment. However, when projected development is normalized against the null scenario (development expected with no treatment), the simulations indicate that conventional systems will increase cumulative basal area increment (CBAI) slightly more, although this difference was not statistically significant. Aboveground biomass production is accelerated 5.1% for SCE and 1.9% for conventional treatments compared to no treatment scenarios.
Neither SCE nor conventional treatments resulted in projected basal area or biomass values that exceeded those projected for “no treatment” scenarios. However, basal area in SCE units recovered to within 89% of the no-treatment scenario, whereas conventional units recovered to within 77% on average. After 50 years SCE results in aboveground biomass that is 91.4% of that projected under no treatment, while the conventional treatments result in 79.1% of the no treatment potential. These differences were statistically significant ($\alpha = 0.05$).

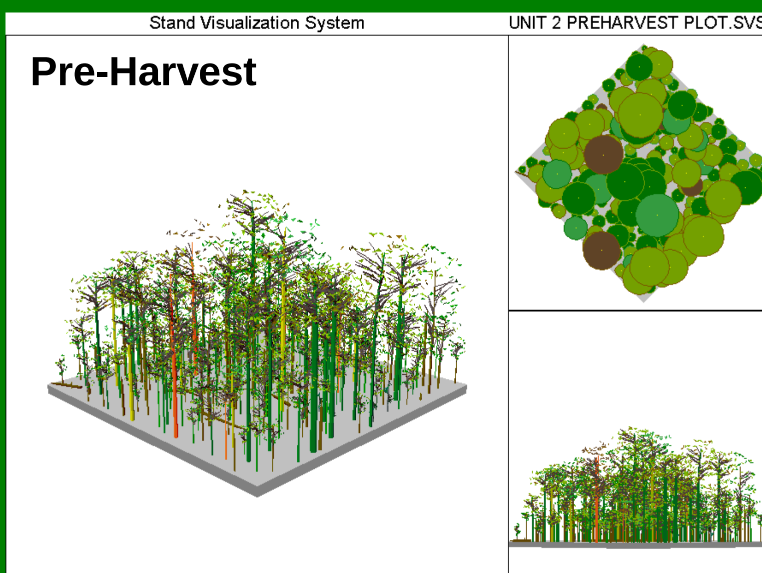
SCE is projected to enhance rates of large tree recruitment over no treatment scenarios. There will be an average of 5 more large trees (> 50 cm dbh) per ha than there would have been without treatment after 50 years in SCE units. There will be 10 fewer large trees/ha on average in the conventional units than would have developed in the absence of timber harvesting. Projections suggest that a rotated sigmoid diameter distribution will be sustained over 50 years in SCE units. The corresponding projected basal area distributions indicate significant reallocation of basal area and biomass into the largest size classes (e.g. > 50 cm dbh) for SCE.

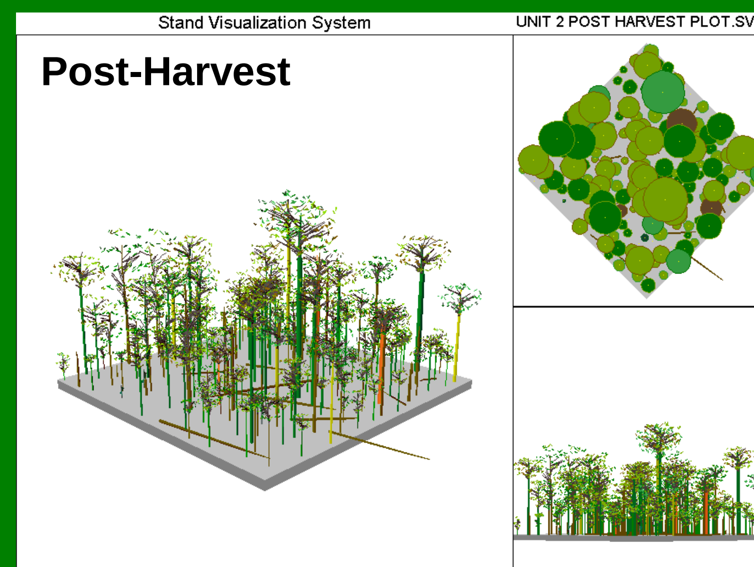
Single-Tree Selection Unit



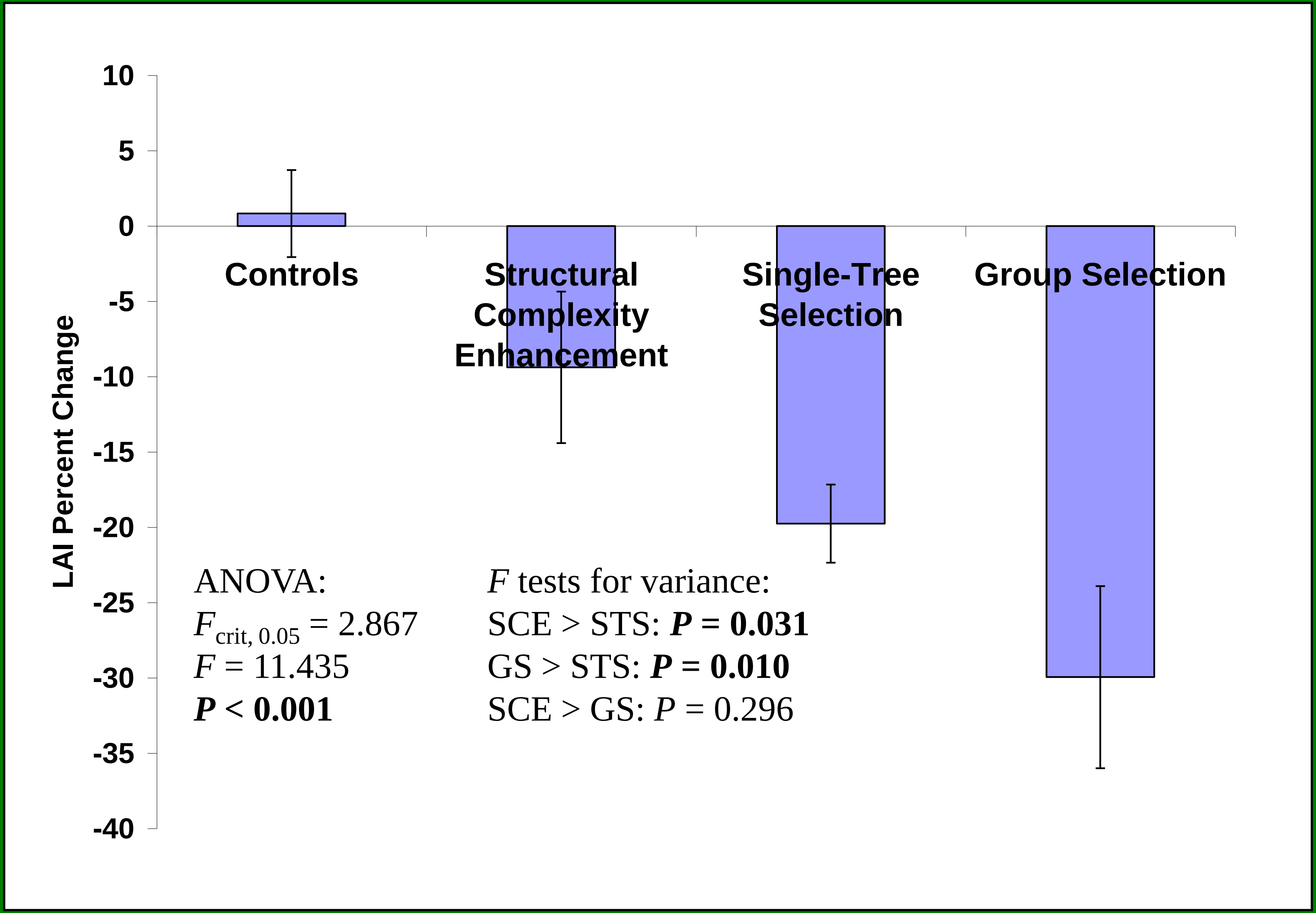


Structural Complexity Enhancement Unit

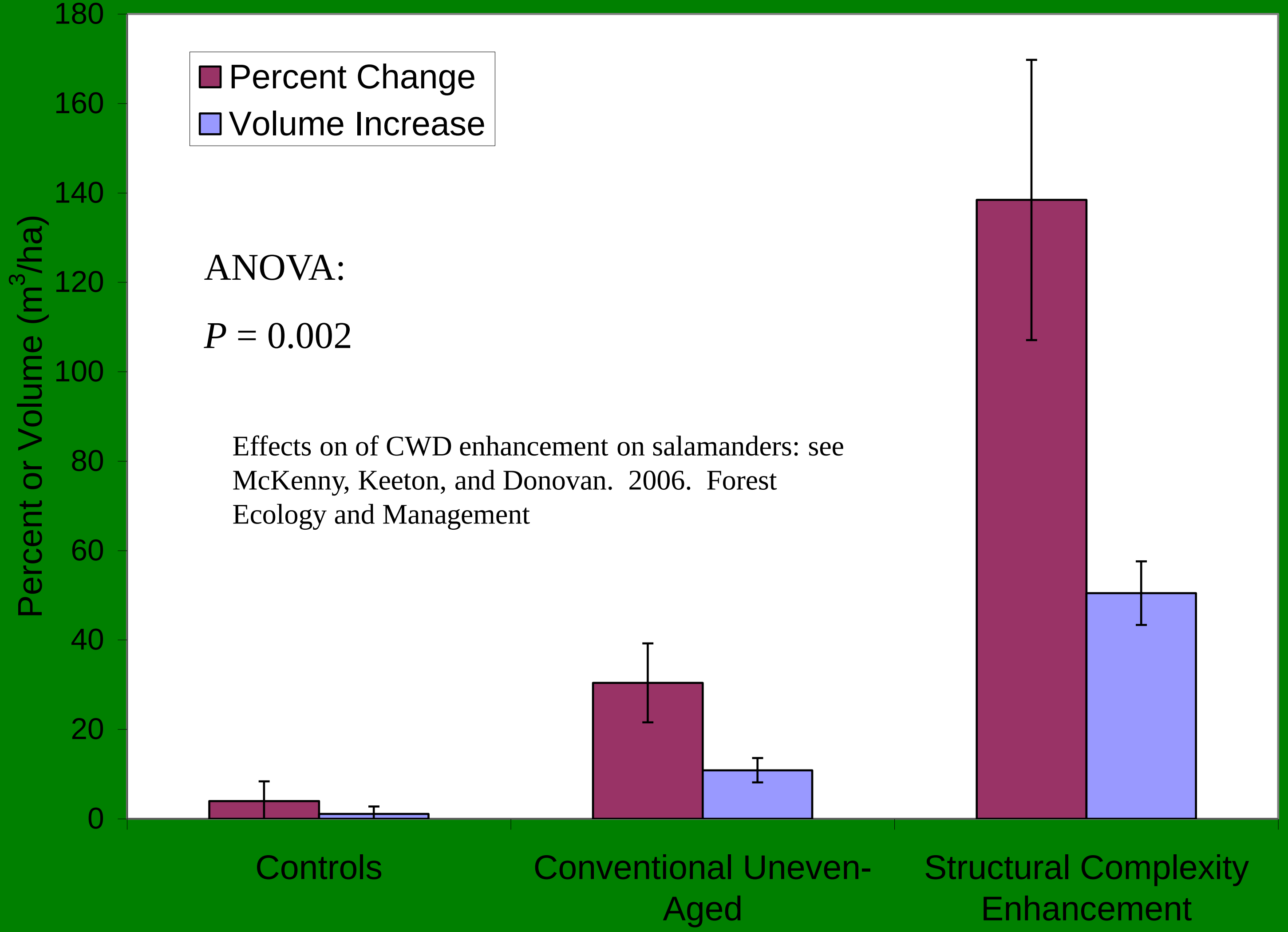




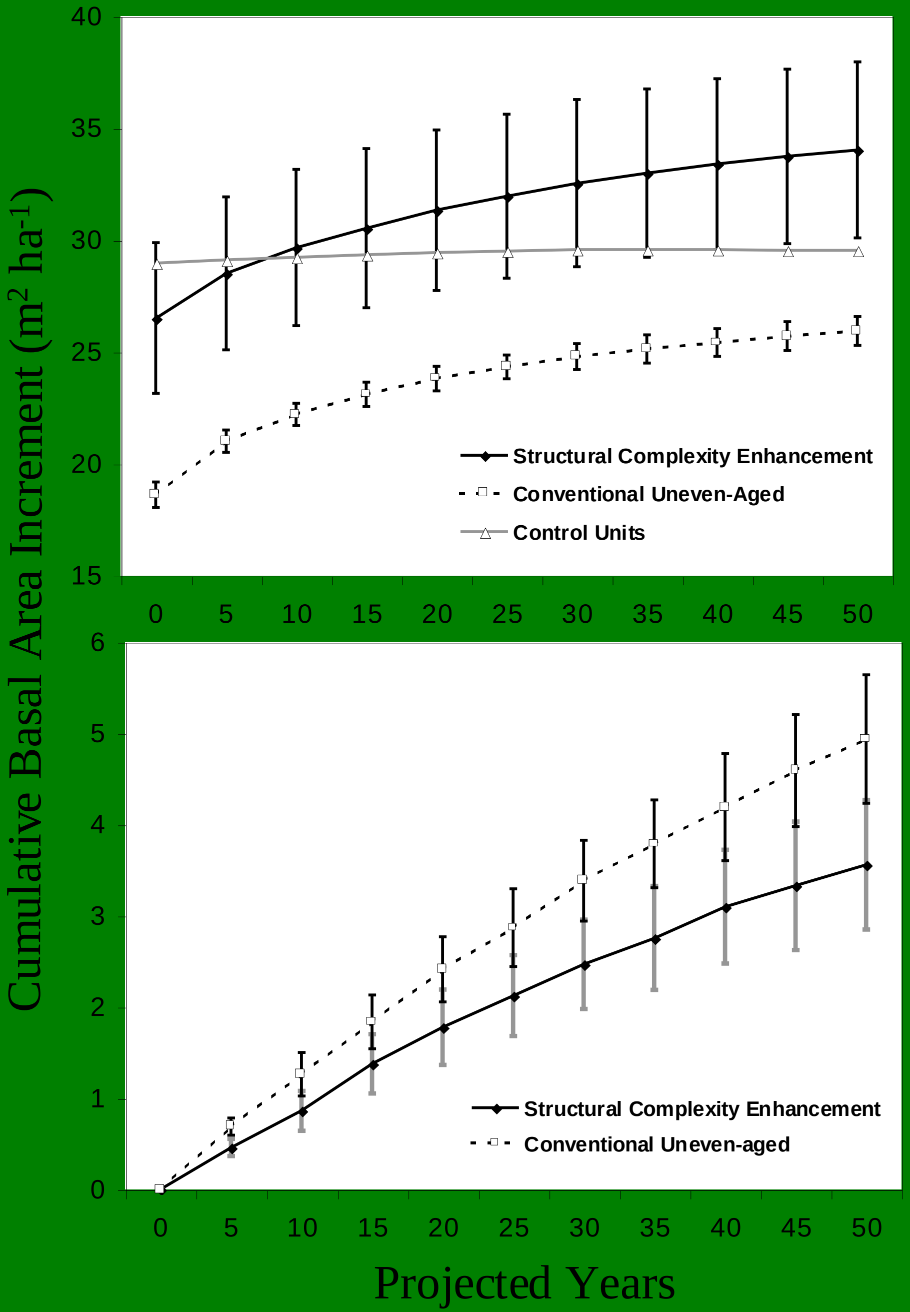
Leaf Area Index Changes: Pre-Treatment to Post-Treatment



CWD Enhancement: Volumes



Cumulative Projected Total Basal Area

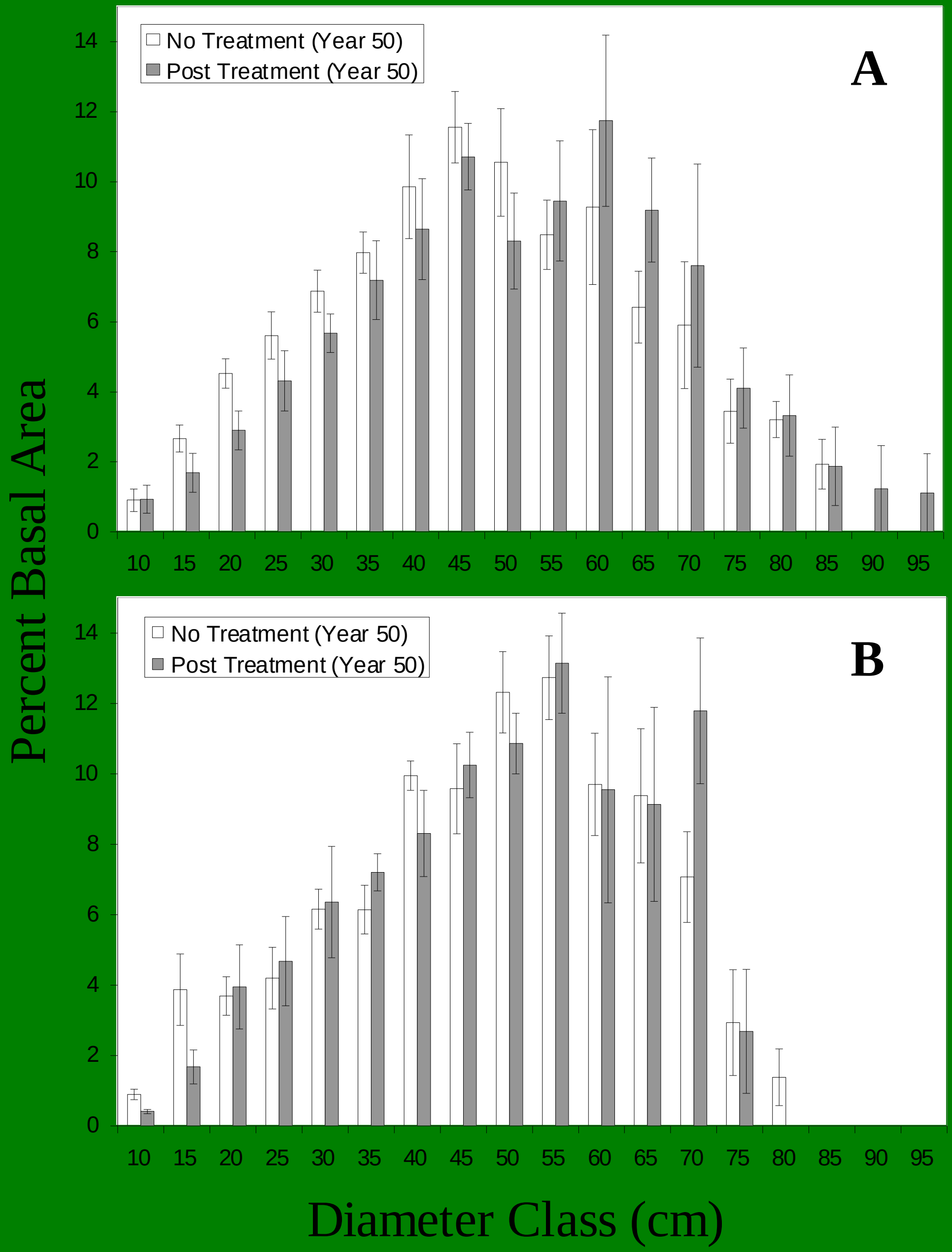


How much have we accelerated growth rates?

Normalized cumulative BAI: “treatment BAI” minus “no treatment BAI” at each time step

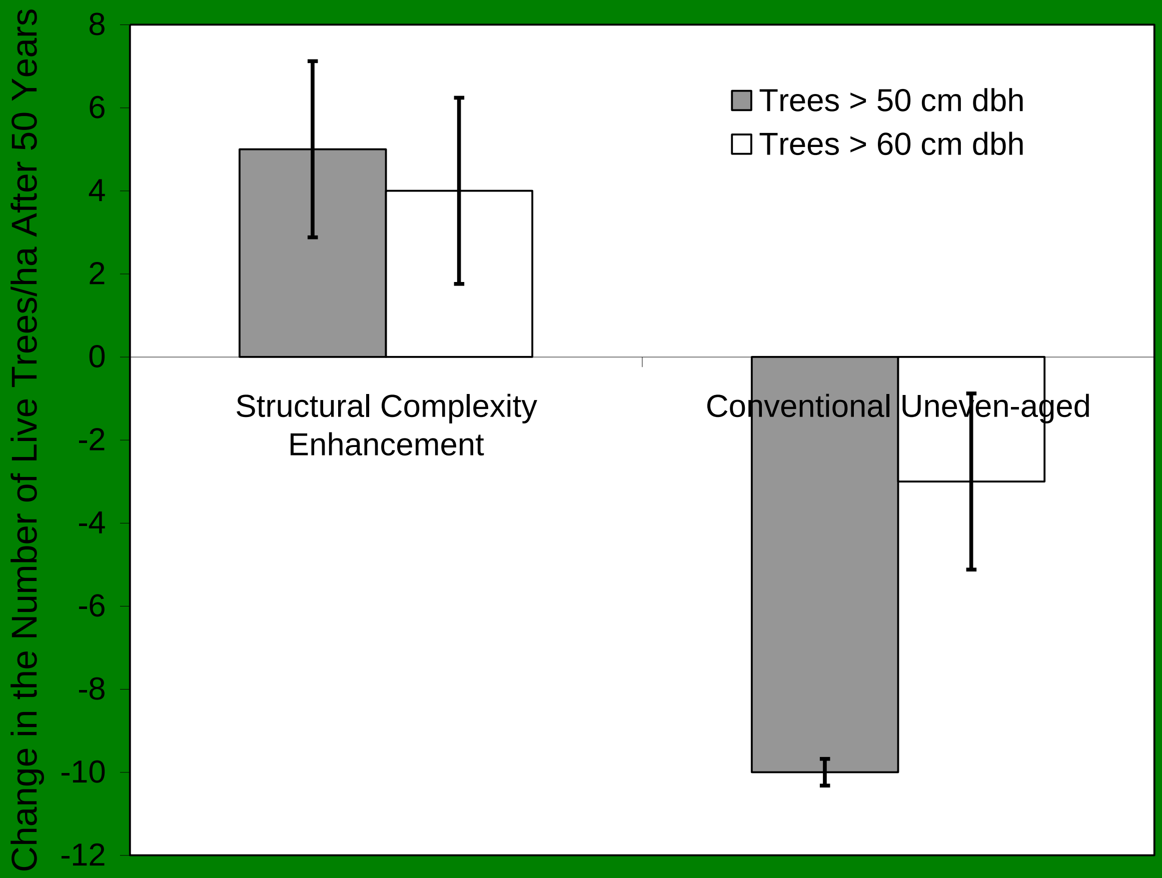
Keeton. 2006. Forest Ecology and Management

Basal Area Allocation by Year 50; Treatment vs. No Treatment Scenarios



Keeton. 2006. Forest Ecology and Management

Projected change in large tree densities after 50 years



P = 0.048 (Trees > 50 cm dbh)

P = 0.042 (Tree > 60 cm dbh)

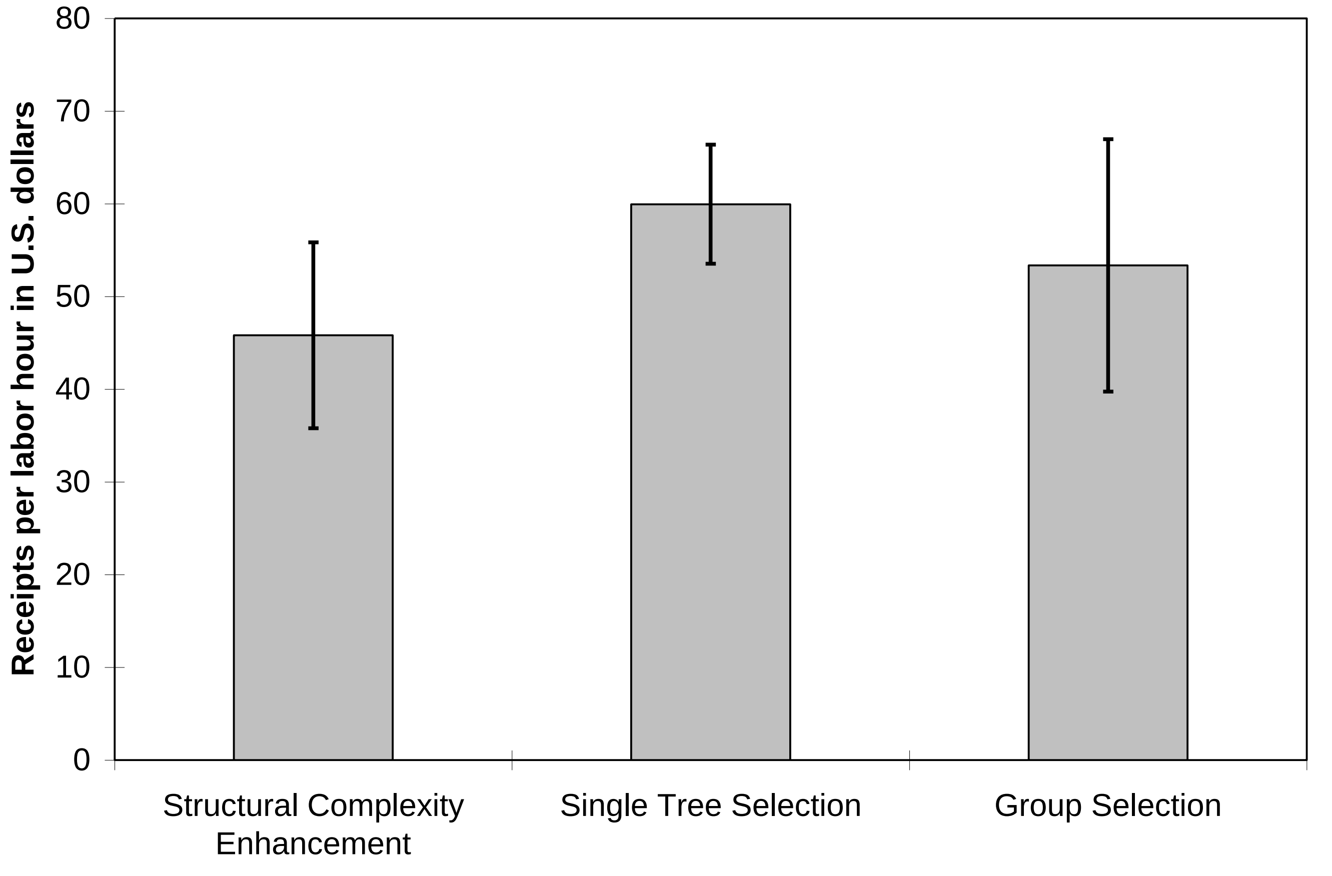
Results: Economic return

Profit margins were highly variable between units due to differences in site quality and treatment prescriptions. Pre-harvest timber volume (and associated surplus available for harvest) was strongly related to revenue for both SCE ($r^2 = 0.56$) and conventional treatments ($r^2 = 0.71$). Thus, site quality accounted for the most variability in harvest revenue among similarly treated units. Single-tree selection resulted in the highest net profits, but was also randomly assigned to units with the highest pre-treatment volumes and greater harvesting opportunities. Average revenue generated per ha. for this treatment was $4,150. Group-selection provided a moderate profit margin but, under a "for profit" scenario, incurred a deficit in one unit where pre-harvest volume was low. Group-selection generated an average revenue of $2,930 per ha. SCE revenues ranked lowest among the treatments, producing $1,710 per ha.

Net profits for SCE varied by treatment unit and cost scenario. Under a "for profit" scenario, net profits for SCE were only positive for sites with higher pre-treatment timber quality. If marking and incidental costs were not considered, SCE resulted in a net profit for all but one unit, where a $425/ha. deficit was incurred. Under favorable cost and site-quality (e.g. top two highest grossing units per treatment) scenarios, net profits per ha. for single-tree selection, group selection, and SCE were $1,550, $900, and $300 respectively. Since these margins include labor costs, they represent profits that would be returned to a landowner after logging contractors have been paid. Sensitivity analysis showed that reducing labor costs by even a small amount would result in profitability for marginal SCE units under all cost scenarios.

Assessing revenues as a ratio relative to the number of labor hours necessary to conduct a treatment provides a different picture of economic feasibility (see next slide). Whether a silvicultural approach is more expensive to implement is a critical question. When we control for differences in operability between sites, SCE had a revenue to labor ratio that was 81% of the average for conventional treatments. From this standpoint SCE may result in a small increase in labor costs relative to conventional treatments.

Receipts per labor hour by treatment



Implications and applications in the Northern Forest region

- Silvicultural techniques can be used effectively to promote old-growth structural characteristics in northern hardwood and mixed northern hardwood-conifer forests. Both the uneven-aged and structural complexity enhancement (SCE) systems tested maintain high levels of post-harvest structure and canopy cover. However, SCE maintains, enhances, or accelerates develop of CWD, canopy layering, overstory biomass, large tree recruitment, and other structural attributes to a greater degree.

- SCE results in a rotated sigmoid diameter distribution that appears sustainable at least over 50 years, and consequently reallocates growing space and aboveground structure into larger size classes. This contributes to enhanced large tree structure, foliage biomass, and associated canopy complexity.

- None of treatments are likely to develop basal areas or aboveground biomass and carbon storage exceeding levels that would have accumulated without treatment. Passive restoration may ultimately develop higher levels of these characteristics. However, that conclusion does not account for the accelerated rates of large tree recruitment, reallocation of basal area, and associated structural complexity projected for SCE. Active restorative approaches thus offer advantages with respect to development of canopy complexity and large tree structure.

- Forest managers have the flexibility to manage for a wide range of structural characteristics and associated ecosystem functions. Uneven-aged systems provide some but not all of these or provide them to a more limited extent. Maximum diameter limits significantly retard the potential for large tree (live and dead) recruitment based on the results. Stand development is thus continuously truncated by multiple uneven-aged cutting entries.

- The results show that SCE's marking guide can be used to successfully achieve a rotated sigmoid diameter distribution. Unconventional prescriptive diameter distributions, such as the rotated sigmoid, combined with higher levels of residual basal area, very large (or no) maximum diameters, and crown release are alternatives for retaining high levels of post-harvest structure and for promoting accelerated stand development.

APPLICATION OF STRUCTURAL COMPLEXITY ENHANCEMENT

Application	# Entries	Late-Successional Structural Development
Old-growth promotion	One or possibly two entries	High
Riparian management	Single or multiple	Moderate to high
Timber emphasis	Multiple	Low to moderate

Future directions

- As a long-term study, continued monitoring and analysis will be necessary to validate predicted stand development and tree growth responses to experimental treatment.
- Biodiversity and process (e.g. soil nutrient dynamics) variables assessed to date capture only short term responses to timber harvest. Yet these variables are known to have complex responses over longer time frames. Thus, continued monitoring will be important to distinguish short-term, transient effects from longer-term effects, modes of recovery, and development trajectories.
- Replication of the study across a wider range of sites would make the results and related inferences more robust. FEMDP researchers hope to add additional sites as funding allows.
- Preliminary results suggest that the FEMDP treatments have important implications for managing forest carbon sequestration. If funding allows, FEMDP researchers plan to expand on the analyses conducted to date by exploring further the complex carbon fluxes and sequestration tradeoffs involved in alternate forest management scenarios. The FEMDP will help inform policy debates regarding the effectiveness of different approaches to managing forest carbon in the northern forest region.

List of products

Publications:

Key: [1] Peer-reviewed journal article

[2] Refereed USDA Forest Service General Technical Report

[3] Peer-reviewed book chapter

[4] Conference proceedings, not peer-reviewed

Smith, K.J., W.S. Keeton, M. Twery, and D. Tobi. In Press. Understory plant response to alternative forestry practices in northern hardwood-conifer forests. Canadian Journal of Forest Research. [1]

North, M.P. and W.S. Keeton. Emulating natural disturbance regimes: an emerging approach for sustainable forest management. Chapter 17 in: R. Lafortezza, J. Chen, G. Sanesi, and T. R. Crow (eds.). Patterns and Processes in Forest Landscapes - Multiple Use and Sustainable Management. International Union of Forest Research Organizations. Vienna, Austria. [3]

Keeton, W.S. 2007. Role of managed forestlands and models for sustainable forest management: perspectives from North America. George Wright Forum 24(3):38-53. [1]

Keeton, W.S. Role of managed forestlands and models for sustainable forest management: perspectives from North America. 2007. Pages 73-87 in: Y. Tunytsya and I. Soloviy (eds.). Proceedings of the international conference on a Global Environmental Convention. Ukrainian National Forestry University, Sept. 28-29, 2006, L'viv, Ukraine.[4]

Keeton, W.S. 2006. Managing for late-successional/old-growth characteristics in northern hardwood-conifer forests. Forest Ecology and Management 235: 129-142. [1]

McKenny, H.C., W.S. Keeton, and T.M. Donovan. 2006. Effects of structural complexity enhancement on eastern red-backed salamander (Plethodon cinereus) populations in northern hardwood forests. Forest Ecology and Management 230: 186-196. [1]

Keeton, W.S. and A. R. Troy. 2006. Balancing ecological and economic objectives while managing for late-successional forest structure. Pages 21-33 in: L. Zahoyska, editor. Ecologisation of economy as a key prerequisite for sustainable development. Proceedings of the international conference, Sept. 22 –23, 2005, Ukrainian National Forestry University, L'viv, Ukraine. [4]

Keeton, W.S. 2005. Managing for old-growth structure in northern hardwood forests. Pages 107-117 in: C.E. Peterson and D.A. Maguire (eds.). Balancing ecosystem values: innovative experiments for sustainable forestry. USDA Forest Service General Technical Report PNW-GTR-635. [2]

Keeton, W.S. 2005. Managing for old-growth structure in northern hardwood forests. Pages 6-11 in: K.P. Bennet (tech. ed.). Moving toward sustainable forestry: lessons from old-growth forests. Proceedings of the 6th eastern old-growth conference, Moultonborough, NH. University of New Hampshire Cooperative Extension Natural Resource Network Report. [4]

.

List of products

Graduate Theses:

McKenny, H. 2005. Effects of structural complexity enhancement on eastern red-backed salamander (*Plethodon cinereus*) populations in northern hardwood forests. Masters Thesis. University of Vermont, Burlington, VT. 59 pp.

Williams, L. 2006. Structural complexity enhancement in northern hardwoods: simulation of stand development effects using SORTIE and the structural complexity index. Masters Thesis. University of Vermont, Burlington, VT. 111 pp.

Smith, K.J.. 2007. Understory plant response to alternative forestry practices in northern hardwood-conifer forests. Masters Thesis. University of Vermont, Burlington, VT. 89 pp.

Publications in preparation:

Keeton, W.S., H. McKenny, D. R. Tobi, and B. Materick. Soil nutrient, disturbance, and compaction responses to low intensity uneven-aged silvicultural practices in northern hardwood forests. Manuscript in preparation for Forest Science.

Tobi, D.R. and W.S. Keeton. Soil invertebrate responses to modified uneven-aged forestry practices in northern hardwood forests. Manuscript in preparation for Forest Ecology and Management.

Williams, L., W.S. Keeton, C.D. Canham, and E. Zenner. Projecting stand development responses to structural complexity enhancement in northern hardwood forests. Manuscript in preparation for Ecological Modeling.

Keeton, W.S., A. Strong, D. Tobi, H. McKenny, and K. Smith. Managing for late-successional biodiversity in northern hardwood forests: biodiversity responses in the Vermont Forest Ecosystem Management Demonstration Project. Manuscript in preparation for Conservation Biology.

Keeton, W.S. and A. Troy. Economic tradeoffs among low intensity, uneven-aged silvicultural alternatives for northern hardwoods. Manuscript in preparation for Northern Journal of Applied Forestry.

.

List of products (Cont.)

Invited Presentations:

Keeton, W.S. Managing forests for carbon storage and resilience to climate change. Vermont Monitoring Cooperative Annual Meeting. Oct 26. 2007, Burlington, Vermont.

Keeton, W.S. Managing for complexity and carbon sequestration in northern hardwood forests. Forest Guild, New England Chapter, Annual Meeting. Sept. 10-11, Fairlee, VT. 2007.

Keeton, W.S. Silvicultural options for managing carbon storage in northern hardwood forests. New England Society of American Foresters, Annual Meeting. March 22, 2007, Fairlee, VT.

Keeton, W.S. Silvicultural alternatives for late-successional forest management in northern hardwood-conifer forests. University of Maine, School of Forest Resources, 2007 Seminar Series. January 2007, Orono, Maine.

Keeton, W.S. The role of managed forestlands in environmental sustainability: perspectives from the United States of America. Conference on the Global Environmental Convention. Ukrainian National Forestry University. Sept. 26-30, 2006, L'viv, Ukraine.

Keeton, W.S. and A. R. Troy. Balancing ecological and economic objectives while managing for late-successional forest structure. International Conference on Ecologisation of economy as a key prerequisite for sustainable development. Ukrainian National Forestry University. Sept. 23, 2005. L'viv, Ukraine.

Keeton, W.S.   Lessons from the Vermont Forest Ecosystem Management Demonstration Project. "Lessons from Large-Scale Manipulations of Ecosystems and Landscapes," Invitational workshop held at the Ecological Society of America 90th Annual Conference. April 7, 2005, Montreal, Canada.

Keeton, W.S. Using restoration to accelerate late-successional/old-growth forest development. Late-Successional/Old-Growth Dialogue. National Commission on Science for Sustainable Forestry & Manomet Center for Conservation Sciences, April 27-28, 2005, Portland, ME.

Keeton, W.S. Structure-based forestry alternatives for northern hardwoods. Oral presentation and field tour for the Society of American Foresters, Green Mountain Chapter, September 16, 2005. Under Hill Center, VT.

Keeton, W.S. Managing for old-growth structure in northern hardwood forests. The 6th eastern old-growth conference – Moving toward sustainable forestry: lessons from old-growth forests. September 23-26, 2004, Moultonborough, NH.

Keeton, W.S. Restoration of old-growth forests based on research in successional and natural disturbance ecology: lessons from the Pacific Northwest and northern New England. Cornell University, Department of Natural Resources, 2004 Seminar Series. September 14, 2004, Ithaca, New York.

Keeton, W.S. Sustainable management of matrix forests as a measure of conservation success, with a focus on forest-stream linkages. Conservation Biology Seminar Series, University of Vermont, Rubenstein School of Environment and Natural Resources. November 4, 2004, Burlington, VT.

List of products (Cont.)

Invited Presentation (Continued):

Keeton, W.S. The Vermont Forest Ecosystem Management Demonstration Project Area. Presentation and field tour for the Vermont Agency of Natural Resources and Vermont County Foresters. December 3, 2004. Mount Mansfield State Forest, VT.

Keeton, W.S. Structure-based forestry: balancing multiple objectives in managed stands. USDA Forest Service, Green Mountain National Forest, Planning Advisory Group ("Blueberry Hill Group"). January 27th, 2004, Barre, VT.

Contributed Presentations:

Keeton, W.S. Restoration of old-growth forest structure in the northeastern United States: experimental evaluation of silvicultural options. Ecological Society of America 92nd Annual Conference. August 5-10, 2007, San Jose, CA.

Smith, K. and W.S. Keeton (presenter). Understory plant responses to alternate uneven-aged silvicultural practices in northern hardwood forests. Ecological Society of America 92nd Annual Conference. August 5-10, 2007, San Jose, CA.

Williams, L. and W.S. Keeton. Measurement and modeling of vertical structure responses to structural complexity enhancement treatments in northern hardwood forests. Ecological Society of America 90th Annual Conference. August 7-12, 2005, Montreal, Canada.

McKenny, H.C. and W.S. Keeton. Effects of structural complexity enhancement on red-backed salamanders (*Plethodon cinereus*) in northern hardwood forests. Ecological Society of America 90th Annual Conference. August 7-12, 2005, Montreal, Canada.

Keeton, W.S. Managing for late-successional structural complexity: a key element of matrix management in the northern hardwood region. 5th North American Forest Ecology Workshop. June 12-16, 2005, Aylmer, Quebec, Canada.

Keeton, W.S., H. McKenny, C.W.Kilpatrick, B. Materick, M. Skinner, A. Strong, D. Tobi, A. Troy, and L. Williams. Vermont Forest Ecosystem Management Demonstration Project: Year 5 results. Annual Meeting of the Vermont Monitoring Cooperative. October 14, 2005, Burlington, VT.

Keeton, W.S. Managing for old-growth structure in northern hardwood forests. Balancing ecosystem values: innovative experiments for sustainable forestry, IUFRO (International Union of Forest Research Organizations) International Workshop. August 15-10, 2004, Portland, OR.

Keeton, W.S., H. McKenny, C. Danks, C.W.Kilpatrick, B. Materick, M. Skinner, A. Strong, D. Tobi, A. Troy, and L. Williams. Vermont Forest Ecosystem Management Demonstration Project. Annual Meeting of the Vermont Monitoring Cooperative. October 8, 2004, Burlington, VT.

List of products (Cont.)

Leveraged Grants:

- Northeastern States Research Cooperative. 2007-2009. Quantification of long-term forest carbon dynamics and net carbon storage under alternate forest management scenarios in the northern forest region – $50,000. W. S. Keeton (P.I.); Co-P.I.: J. Jenkins.

- Northeastern States Research Cooperative. 2007- 2010. Soil carbon and other quality indicators in managed northern forests. Donald Ross and Sandy Wilmot (P.I.'s); Co-P.I.'s: C. Alves, J. Briggs, D. Brynn, N. Kamman, W.S. Keeton, and T. Villars.

- Trust for Mutual Understanding, 2006-2008. Integrating ecological economics and sustainable forest management into Ukraine's transition economy: an international scientific exchange – $25,000. W.S. Keeton (P.I.); Co-P.I.'s: D. Bergdahl, Y. Bihun, M. Chernyavskyy, R. Costanza, Joshua Farley, L. Maksymiv, S. Myklush, I. Soloviy, and L. Zahoyska.

- Northeastern States Research Cooperative, 2006-2007. Developing management guidelines for conserving late-successional forest in the Northern Forest region – $177,000. J. M. Hagan (P.I.); Co-P.I.'s: W.S. Keeton (P.I. for $20,000 sub-contract), G. McGee, and A. Whitman.

- The Vermont Monitoring Cooperative, 2006-2007. The Vermont Forest Ecosystem Management Demonstration Project – $8,000. W.S. Keeton (P.I.).

- The Vermont Monitoring Cooperative, 2005-2006. The Vermont Forest Ecosystem Management Demonstration Project – $8,000. W.S. Keeton (P.I.).