Long-term research on classical silvicultural approaches in the Acadian Forest: Penobscot Experimental Forest Part I

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Abstract

The most comprehensive study of stand dynamics in the Acadian Forest Region is an experiment by the USDA Forest Service at the Penobscot Experimental Forest (PEF) in Maine. It was established from 1952-1957 to study changes in structure, composition, and productivity from an array of silvicultural treatments. Ingrowth, accretion, and mortality of individual trees (≥0.5 in. dbh) are followed on permanent sample plots before and after harvests, and at about 5-year intervals between harvests. Differences in growth between the reference and treated stands and among several of the treatments have been documented. There have also been changes in species composition and stand quality. Over the decades this experiment has yielded valuable answers to questions it was designed to address and insights into many issues that were not anticipated when it was planned. In addition, it has been the stage for a broad range of short-term ecological and management studies.

Keywords: silviculture, long-term research, northern conifers

Background

The Acadian Forest is one of many regions in Canada and includes much of northern and eastern Maine. The region is notable for its proximity to the Atlantic Ocean and the influence that location has had both ecologically and historically. The climate is somewhat moderated for its latitude and proximity to ports has meant a long history of earlier exploitation and more recent management of the forests. The Acadian Forest Region is a transition zone between eastern broadleaf and boreal forests. Fire frequency is low compared to neighboring regions. Stands are often dominated by conifers, especially spruces (*Picea* spp.), red spruce (*P. rubens*) is the "signature species" for the region; balsam fir (*Abies balsamea*); pine (*Pinus* spp.), primarily eastern white pine (*P. strobus*); northern white-cedar (*Thuja occidentalis*); eastern hemlock (*Tsuga canadensis*) in the southern portion of the region and tamarack (*Larix laricina*) more to the north. Hardwood associates include: red maple (*Acer rubrum*); birches (*Betula* spp.), mostly paper (*B. papyrifera*) and gray (*B. populifolia*); and aspen (*Populus* spp.), both trembling (*P. tremuloides*) and bigtooth (*P. grandidentata*). Largely because precipitation is well distributed throughout the year, natural regeneration is prolific. The combination of a preponderance of shade tolerant species (spruce, fir, and hemlock) and abundant regeneration makes the Acadian Forest a silviculturist's dream – almost the full array of classical silvicultural systems, both even-aged and uneven-aged are appropriate. Seed tree is one method that is seldom used because the soils and the root systems of most of the conifers that grow well in the region are shallow. Consequently, scattered individual trees are susceptible to blowdown.

The Penobscot Experimental Forest (PEF) is in the towns of Bradley and Eddington, in east-central Maine, across the Penobscot River from Orono and the University of Maine campus. The PEF was established in 1950. It was purchased by nine timberland owners in Maine and leased to the Northeastern Forest Experiment Station (now Northern Research Station) of the USDA Forest Service as a location for timber management research in northeastern spruce-fir forests. In 1994 the industrial owners donated the property to the University of Maine Foundation. Research on the forest is managed jointly by a team of university faculty and Forest Service researchers.

Today the PEF is one of the premier centers for research and demonstration on sustainable forestry in the Northeast. There is large-scale, long-term research being conducted by scientists from the Northern Research Station and by faculty and grad students from the University of Maine; much of the research is collaborative. This paper is the first of two companion articles and focuses on a long-term experiment that the Forest Service started in the 1950s with an array of classical silvicultural treatments. The companion paper (this volume) by Wagner and others describes a long-term study started about 10 years ago by university researchers to compliment the Forest Service study using concepts of disturbance-based silviculture.

The Forest Service planned and established the initial experiment to address the industrial landowners' concerns. Their focus was on producing wood efficiently and economically. The response variables were simple, just basic mensurational data were considered. There were no plans to measure effects on coarse woody material, biodiversity, root development, leaf area and growth efficiency, and the myriad of other responses that have been followed in this experiment over the years. Why has this experiment and others like it been so enduring – and so valuable –

for over 50 years? The reasons can best be explored by evaluating elements of the study design and some of the results.

Long-Term Silvicultural Study

The experimental units, called compartments, were relatively large, averaging over 20 acres in size. Treatments were replicated, only twice, but replicated. This was one of the first replicated studies in the northeast. The study has an array of treatments, including classical silvicultural methods like shelterwood and selection and removal-driven practices like commercial clearcutting and diameter-limit cutting (table 1).

Table 1. Initial treatments included in long-term silvicultural experiment at the Penobscot Experimental Forest in Maine.

System/Method	Code	Compartment (number)	Size (ac)	First inventory
Even-aged				
Unregulated harvesting	URH	8	43	1953
(commercial clearcutting)		22	34	1956
Uniform Shelterwood				
Two-stage	SW2	21	27	1956
		30	18	1957
Three-stage	SW3	23	24	1954
		29	17	1957
Unveven-aged (Selection)				
5-year cutting cycle	S05	9	27	1953
		16	16	1957
10-year cutting cycle	S10	12	31	1954
		20	21	1957
20-year cutting cycle	S20	17	26	1954
		27	20	1957
Diameter-limit cutting				
Fixed by species	FDL	4	25	1952
		15	26	1955
Modified	MDL	24	26	1955
(flexible by species)		28	18	1957
Unmanaged reference	NAT	32a	13	1954
		32b	5	1954

In the 1980s the Three-stage shelterwood compartments were split and precommercial thinning applied to half. In 2004 one of the precommercially thinned compartments was included in a state-wide commercial thinning study.

A system of permanent sample plots was randomly located throughout each compartment. An average of 18 sample plots per compartment provide an area sample of about 15% for trees ≥ 4.5 in DBH, 4% for saplings, and 0.25% for seedlings. Inventories have been taken before and after harvests and at about 5-year intervals between cuts (figure 1).

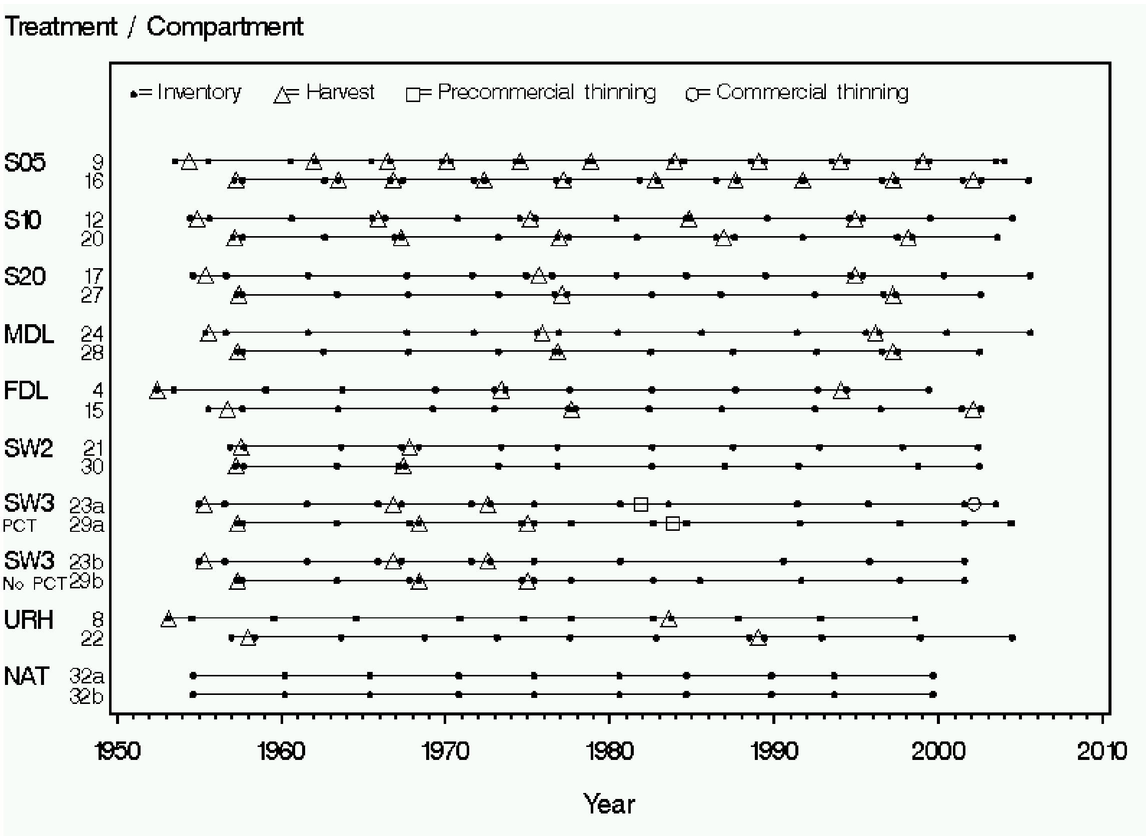

Figure 1. Timeline of activities in the long-term silvicultural experiment at the Penobscot Experimental Forest in Maine.

Regeneration inventories began in mid-1960s. Repeated measurements of individual tree (DBH > 0.5 in.) began in mid-1970s.

The treatments and inventories have been faithfully applied over the years, resulting in a long-term record of stand dynamics by treatment and compartment or replicate. This is one of only a handful of studies in North America with such a dataset, especially considering that trees down to the 1 inch class have been followed.

Results – Some Examples

In terms of the original goals of the study, the compartments regenerated by shelterwood are about half way through an even-aged rotation so it is too early to answer many of the questions the experiment was designed to address. Nevertheless, results through 40 years have been presented by Sendak and others (2003). After 40 years there were few significant differences in growth, largely because with only two replicates the experiment has little power to detect differences. Other reasons for the lack of treatment differences were that the shelterwood treatments were still largely composed of sapling and small poles so had little measurable basal area or volume growth and in the selection compartments most of the growing stock was there when the experiment began; that is, there has been little recruitment into the pole and small sawtimber classes where basal area and volume growth are usually most rapid.

However, some trends were evident. Species composition and stand quality have been clearly impacted. Because of its greater longevity and resistance to spruce budworm (*Choristoneura fumiferana*), spruce is favored over balsam fir, while compared to hemlock, spruce is favored because of its better commercial wood properties. In those treatments where species could be favored (i.e., selection and the overstory removal phase of three-stage shelterwood), the spruce component (percent basal area) increased compared to the initial inventories. In the removal-driven treatments (unregulated harvest and fixed diameter-limit), the spruce component decreased. Spruce basal area also declined in the unmanaged reference compartments. The selection and shelterwood treatments reduced the proportion of cull trees (<50 percent sound volume), while in treatments that did not specifically target cull trees for removal (unregulated harvest, diameter-limit cutting) the percentage of cull increased.

In addition to the overall summary by Sendak and others (2003), Kenefic and others (2005) presented a detailed comparison of fixed diameter-limit and selection cutting. Both treatments had been cut three times at about 20 year intervals. The initial advantage diameter-limit cutting had in terms of early value removals and ease of application have been offset by less desirable stand conditions that limit future benefits. After 45 years, repeated diameter-limit cutting resulted in lower residual stand volume and value, a higher proportion of unmerchantable growing stock, less medium to large sawtimber growth and harvest, and less dense regeneration. Consequently, after three harvests there are fewer management options and less silvicultural flexibility in the diameter-limit treatment than in the 20-year selection treatment.

In addition publishing results in scientific and professional journals, demonstration and technology transfer are important ways knowledge gained from this experiment is made available to foresters and other land managers. Several tours and presentations about the research are given each year. Much of the technology transfer effort has focused on the classical silvicultural methods, shelterwood and selection. Examples of highlights often presented in workshops and on tours include:

Shelterwood:

- Shelterwood harvests released advance regeneration and initiated new seedlings over a period of about 35 years.
- Competition-induced mortality began increasing about 35 years after first stage cuts in both treatments.
- Mortality: hardwoods > balsam fir > spruce = other conifers.
- In SW2, residual overstory prolonged presence of small seedlings and reduced growth rate compared to SW3.
- Species composition influenced more by site and timing of seed crops than treatment.

Selection:

- Regeneration of desired species was prolific following harvests that reduced basal area by as little as 13 ft^2/ac (8-12%).
- Harvest activity reduced seedling density by 13-37%, but numbers recovered within 5 years.
- Sapling growth has been very slow (<0.1 in./yr) and ingrowth into poles and sawtimber lacking.
- Age – size relationships are weak.

For the shelterwood treatments the highlights were based on carefully following the dynamics of developing stands from initiation through stem exclusion. Gaining this kind of knowledge depends on re-measuring permanent sample plots over a long period of time. For selection, the examples above are just some of the things learned. There is much more, the kinds of knowledge that is needed to write silvicultural prescriptions with some certainty that objectives will be met. As with the work in shelterwood silviculture, such knowledge can only be gained through meticulous long-term study. In the case of selection silviculture, it is particularly important that cutting cycles be defined and followed, requiring a long-term commitment and dedicated staff.

Remaining Relevant

The publications and presentations examples given are representative of using results from the experiment to answer some of the questions posed when the study was designed. However, although the treatments have remained constant since the experiment was implemented, many new questions have come up over the course of 50 years. Because of the consistency of treatments and re-measurements, the long-term study has provided answers to questions the original planners could not have anticipated. Here are some published examples from the past 10 years:

> Effects of intensity and frequency of harvesting on abundance, stocking, and composition of natural regeneration (Brissette 1996).
>
> Crown structure and growth efficiency of red spruce in uneven-aged, mixed species stands (Maguire and others 1998).

Balance and sustainability in multi-aged stands (Seymour and Kenefic 1998).

Leaf area prediction models for *Tsuga canadensis* (Kenefic and Seymour 1999).

Precommercial thinning in a northern conifer stand (Brissette and others 1999).

Age-related changes in foliar morphology and physiology in red spruce and their influence on declining photosynthetic rates and productivity (Day and others 2001).

Importance of sampling along a vertical gradient to compare insect fauna in managed forests (Su and Woods 2001).

Influence of age on growth efficiency of *Tsuga canadensis* and *Picea rubens* trees in mixed-species, multi-aged northern conifer stands (Seymour and Kenefic 2002).

A field test of point relascope sampling of down coarse woody material in managed stands (Brissette and others 2003).

Impacts of long-term diameter-limit harvesting on residual stands of red spruce (Sokol and others 2004).

Silviculture alters the genetic structure of eastern hemlock (Hawley and others 2005).

Snag longevity under alternative silvicultural regimes in mixed species forests (Garber and others 2005).

Furthermore, the long-term silvicultural experiment has become an ideal stage for hosting a range of short-term studies on questions never envisioned by the original planners – fundamental questions about tree growth both above and below ground, patterns and processes of stand development, effects of management on biodiversity, and lots of sophisticated quantitative analyses and modeling efforts. Following is a list of some of the graduate student studies that have been overlaid on the long-term silvicultural experiment in recent years:

Modeling early regeneration processes in mixed species forests of Maine: germinant emergence and early survival. Geoffrey Wilson, M.S. University of Maine, 1997.

Insect biodiversity in managed forests. Jeffrey Jaros-Su, Ph.D. University of Maine, 1999.

Factors influencing net primary production in red spruce. Michael Day, Ph.D. University of Maine, 2000.

Leaf area, stemwood volume growth, and stand structure in a mixed-species, multi-aged northern conifer forest. Laura Kenefic, Ph.D. University of Maine, 2000.

Implications of long-term diameter-limit harvesting: effects on radial growth of red spruce and genetic diversity of white pine. Kerry Sokol, M.S. University of Maine, 2001.

Effect of precommercial thinning on root development and root and butt decay incidence of red spruce and balsam fir. Suzhong Tian, Ph.D. University of Maine, 2002.

Crop tree growth and quality twenty-five years after precommercial thinning in a northern conifer stand. Leah Phillips, M.S. University of Maine, 2002.

Understory growth dynamics and mensuration techniques in uneven-aged, mixed species northern conifer stands. Andrew Moores, M.S. University of Maine, 2003.

Age related trends in red spruce needle anatomy and the relationship to declining productivity. Margaret Ward, M.S. University of Maine, 2005.

A physiological examination of the age-related decline in photosynthesis in red spruce (*Picea rubens*). Stephanie Adams, M.S. University of Maine, 2006.

Dynamics of forest structure under different silvicultural regimes in the Acadian Forest. Michael Saunders, Ph.D. University of Maine, 2006

These studies were typically two to four years in duration and would not have been possible if it had not been for the presence of the long-term experiment. The long-term study continues to generate new ideas and new studies, all of which adds to our knowledge of tree growth and stand dynamics. Thus, long-term studies are one component, although key, in the larger suite of methods used by researchers to answer questions and advance our knowledge of forest ecology and management.

Summary

To summarize, we return to the question: Why has this experiment been so enduring and valuable for over 50 years? We believe lessons from the PEF long-term silvicultural experiment provide several key answers to that question:

Empirical studies alone cannot explain the complex interactions among site attributes and forest vegetation in multi-aged, mixed species stands. We need more process-oriented research, like many of the graduate student studies, to better understand the underlying mechanisms that lead to the observed effects of silvicultural treatments.

Long-term research is essential because natural processes are too complex and unpredictable to be modeled based on observations at one or a few points in time. Our goal is to provide forest managers the knowledge needed to prescribe treatments with a reasonable level of certainty that they can achieve desired outcomes.

Without long-term research, there are no benchmarks to measure natural or anthropogenic changes; i.e., one critical benefit of long-term research is as a gauge of change.

Another very important thing we have learned from the PEF long-term study is that results after 20 years indicated treatments would have greater influence on stand structure and composition than has been the case. This has caused us to reevaluate the treatments and revise the study plan based on what we have learned.

As the knowledge base expands, managers use that knowledge to inform their actions with ever greater certainty of the outcomes. Thus, a cycle is perpetuated where data is turned into knowledge and knowledge is turned into action.

Literature Cited

BRISSETTE, J.C. 1996. Effects of intensity and frequency of harvesting on abundance, stocking, and composition of natural regeneration in the Acadian Forest of eastern North America. *Silva Fennica* 30(2-3):301-314.

BRISSETTE, J.C., M.J. DUCEY and J.H. GOVE. 2003. A field test of point relascope sampling of down coarse woody material in managed stands in the Acadian Forest. *Journal of the Torrey Botanical Society* 130(2):79-88.

BRISSETTE, J.C., R.M. FRANK, Jr., T.L. STONE and T.A. SKRATT. 1999. Precommercial thinning in a northern conifer stand: 18-year results. *The Forestry Chronicle* 75(6):967-972.

DAY, M.E., M.S. GREENWOOD and A.S. WHITE. 2001. Age-related changes in foliar morphology and physiology in red spruce and their influence on declining photosynthetic rates and productivity with tree age. *Tree Physiology* 21:1195-1204.

GARBER, S.M., J.P. BROWN, D.S. WILSON, D.A. MAGUIRE and L.S. HEATH. 2005. Snag longevity under alternative silvicultural regimes in mixed-species forests of central Maine. *Canadian Journal of Forest Research* 35:787-796.

HAWLEY, G.J., P.G. SCHABERG, D.H. DeHAYES and J.C. BRISSETTE. 2005. Silviculture alters the genetic structure of an eastern hemlock forest in Maine, USA. *Canadian Journal of Forest Research* 35:143-150.

KENEFIC, L.S. and R.S. SEYMOUR. 1999. Leaf area prediction models for *Tsuga canadensis* in Maine. *Canadian Journal of Forest Research* 29:1574-1582.

KENEFIC, L.S., P.E. SENDAK and J.C. BRISSETTE. 2005. Comparison of fixed diameter-limit and selection cutting in northern conifers. *Northern Journal of Applied Forestry* 22(2):77-84.

MAGUIRE, D.A., J.C. BRISSETTE and L. GU. 1998. Crown structure and growth efficiency of red spruce in uneven-aged, mixed-species stands in Maine. *Canadian Journal of Forest Research* 28:1233-1240.

SENDAK, P.E., J.C. BRISSETTE and R.M. FRANK. 2003. Silviculture affects composition, growth and yield in the Acadian Forest: 40-year results from the Penobscot Experimental Forest. *Canadian Journal of Forest Research* 33:2116-2128.

SEYMOUR, R.S. and L.S. KENEFIC. 1998. Balance and sustainability in multi-aged stands: a northern conifer case study. *Journal of Forestry* 96:12-16.

SEYMOUR, R.S. and L.S. KENEFIC. 2002. Influence of age on growth efficiency of *Tsuga canadensis* and *Picea rubens* trees in mixed-species, multi-aged northern conifer stands. *Canadian Journal of Forest Research* 32:2032-2042.

SOKOL, K.A., M.S. GREENWOOD and W.H. LIVINGSTON. 2004. Impacts of long-term diameter-limit harvesting on residual stands of red spruce in Maine. *Northern Journal of Applied Forestry* 21(2):69-73.

SU, J.C. and S.A. WOODS. 2001. Importance of sampling along a vertical gradient to compare insect fauna in managed forests. *Environmental Entomology* 30(2):400-408.