Turning Data into Knowledge for over 50 Years: USDA Forest Service Research on the Penobscot Experimental Forest

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Abstract

Scientists from the Northeastern Research Station of the USDA Forest Service have been conducting long-term silvicultural research on the Penobscot Experimental Forest (PEF) in Maine since the early 1950s. The core experiment, which includes 10 replicated treatments, has generated an extensive dataset on forest response to both silvicultural treatments and exploitative cutting. The PEF research is an important source of information on managing the Acadian Forest, and is the site of additional physiological, ecological, and management studies conducted by Forest Service scientists and cooperators. The value of the core experiment will continue to increase as additional data are collected.

Introduction

In the late 1940s, forest industry in Maine recognized the need for silvicultural research in that region. To meet that need, nine pulp and paper and land-holding companies purchased forest land in the towns of Bradley and Eddington in east-central Maine in 1950. This land was leased to the USDA Forest Service, Northeastern Research Station, for the long-term study of silviculture of northern conifers (called spruce-fir at the time), and became the site of the Penobscot Experimental Forest (PEF). In the mid-1990s, ownership of the PEF was transferred to the University of Maine, which uses the forest for long-term research, education, and income generation. The Forest Service retains control of its long-term experiment, which has been in place for more than 50 years.

Study Area

The PEF is located in the Acadian Forest, an ecotone between the eastern broadleaf and boreal forests that covers much of Atlantic Canada and northern and eastern Maine. Common species in the northern conifer forest of the Acadian region include spruce (red, white, and black), balsam fir, eastern hemlock, northern white-cedar, eastern white pine, and hardwoods such as maples, birches and aspens. Well-drained sites have components of pine and can contain quality northern hardwoods such as sugar maple or yellow birch, and oak species. Moderately well and somewhat poorly drained sites are characterized by eastern hemlock, red spruce, and balsam fir with paper birch. Most of the poorly and very poorly drained sites are dominated by spruce, fir, cedar and red maple.

Natural disturbance regimes are an important mechanism of forest diversity. Small-scale gap dynamics predominate in the Acadian Forest, with spruce budworm outbreaks approximately every 40 years that result in widespread growth suppression and mortality of fir and spruce species (Seymour 1995). The estimated natural return interval for stand-replacing disturbances such as fire exceeds 1,000 years (Lorimer and White 2003). These disturbance patterns result in an irregular multi-aged forest structure and support the presence of shade-tolerant species.

Land-use and forest-management history also have affected composition and structure, often overriding the influence of site and natural disturbance. The Acadian Forest was not cleared extensively for agriculture but instead was partially harvested repeatedly. In particular, 20th century cutting practices that coupled heavy removals with inattention to regeneration have caused significant shifts in regional tree species composition. For example, many formerly softwood sites now contain poor-quality hardwoods. Balsam fir and red maple are the most abundant commercial tree species in Maine, showing the greatest increases in numbers of live trees (Griffith and Laustsen 2001). These state-level trends have generated concern among managers and researchers, so long-term studies of the effects of management and exploitation are critical.

Stand reconstruction suggests that while the 4,000 acres encompassed by the PEF were not cleared for crops or pasture (nor were they burned extensively), they were partially harvested periodically. In fact, in the late 1700s, a mill on the site supported local timber extraction (Hale 2005). But, the forest had not been harvested in the 50 years prior to the Forest Service experiment. Stand reconstruction and historical photographs suggest that the forest was irregularly multi-aged and patchy, with significant components of mature softwood dominated stands in the understory reinitiation phase; see Oliver and Larson (1996) for descriptions of the phases of stand development.

Experimental Design and Methodology

The core experiment on the PEF is the 600-acre silviculture study initiated in the early 1950s. This study includes 10 treatments, each replicated twice at the stand level; the average stand (replicate) area is 25 acres. Although experimental units are clearly recognizable as distinct stands today, they were originally compartments, that is, geometric management units delineated for ease of treatment application without considering natural stand boundaries. There were no significant differences among compartments prior to treatment, but high within-treatment variability compounded by low statistical power (n=2) make it difficult to detect statistically significant differences between treatments today (a characteristic of many of the silvicultural studies initiated in the first half of the 20th century). The control stand, a set aside natural area in 1954, was redefined as two separate compartments in 1994 (Kenefic et al. 2004).

Overstory data are collected on nested 1/50-, 1/20-, and 1/5-acre plots that provide a sampling intensity of up to 15% in each compartment. The first inventories were conducted before the first treatments, providing important baseline data. Trees larger than 0.5 inch dbh on the 1/50-acre, 2.5 inches dbh on the 1/20-acre, and 4.5 inches dbh on the 1/5-acre plots are numbered and species, dbh, and condition are recorded before and after every harvest or silvicultural treatment and at 5-year intervals between treatments (Fig. 1). Treatment application and sample-plot remeasurement have been remarkably consistent and are one of the hallmarks of this study. Data collection has been recently expanded to include subsamples of tree height, crown length and radii, spatial location, and species, size, and condition of snags, logs, and stumps. To accommodate expanded data collection, the remeasurement interval is being increased to 10 years.

Regeneration data have been collected since the 1960s using 3 milacre (1/1000-acre) plots located at the periphery of each 1/20-acre overstory plot. Seedlings (0.5 feet tall to 0.5 inch dbh) are counted by species and height class on these plots; percent ground cover recently was added as a measurement variable. Treatments encompass even-, two-, and uneven-age silvicultural systems and exploitative cutting. The silvicultural treatments include shelterwood with two- and three-stage overstory removals—with and without precommercial and commercial thinning—and selection cutting on 5-, 10-, and 20-year cutting cycles. Modified and fixed diameter-limit cutting and commercial clearcutting, though not silvicultural systems, were included in the study because they were typical of harvests in the region in the late 1940s and 1950s. These are removal-driven harvests in which desired log characteristics at the time of harvest motivate cutting without attention to residual stand condition. Diameter-limit cutting and commercial clearcutting remain common today, and the results of repeated applications from the PEF are valuable for land managers and policymakers. See Sendak et al. (2003) for complete treatment descriptions.

Highlights

Analysis of the effect of treatment on growth over the first 40 years of the study (Sendak et al. 2003) revealed that gross volume growth differed significantly only between the three-stage shelterwood and control. Mortality and net growth did not differ across treatments. Although high within-treatment variability may be masking real differences, these data highlight important considerations about the study design. The stage of stand development greatly affects the outcome of comparisons. For example, in the three-stage shelterwood, all trees > 2.5 inches dbh were removed in the 1960s. These stands were in early stem exclusion for much of the measurement period, with no trees > 4.5 inches dbh until the most recent inventories. Biomass accumulation is high in these young aggrading stands but volume growth (growth of trees > 4.5 inches dbh) is low because most stems do not meet the minimum merchantable diameter. This result is supported by a comparison of recent growth rates. The annual increase in volume over a recent 5-year period indicates that standing volume in the three-stage shelterwood increased by nearly 20 percent but by < 5 percent in multi-aged treatments and < 0.5 percent in the control. As a result, accurate determination of the effects of treatment on the components of growth is not possible until the even-aged stands have been measured for a full rotation. An additional 40 to 50 years of study will be needed before we can answer the fundamental and often asked question: are even- or uneven-aged structures more productive?

Even so, the PEF study has generated useful results to date, providing a long-term perspective on the effects of forest management. For example, the shelterwood treatments have been effective in creating fully stocked stands of tolerant northern conifers except for eastern hemlock. In the three-stage shelterwood the proportions of fir and spruce basal area (BA) for trees >/= 0.5 in dbh have increased over time, while the BA of hemlock is much lower than before treatment (Sendak et al. 2003). Ongoing analysis of these data will enable us to determine the reasons for this trend, which may be related to differences in species-specific harvesting preferences, regeneration success, growth rates, or mortalities.

Another finding from the shelterwood treatments was that failure to harvest unmerchantable trees and undesirable species during overstory removal in the two-stage treatment resulted in the creation of a two-aged stand. Total BA was higher following partial overstory removal in the two-stage than after overstory removal in the three-stage shelterwood treatments. However, by year 45 of the study, it was the same, possibly due to a combination of mortality in poor vigor residuals and the suppression of the younger age class where residuals were retained. Thus, practitioners of two-age silviculture may sacrifice growth on the new cohort, though this might be offset if the residual trees are of high quality and vigor. Longer observation will provide more definitive results. Intermediate treatments (thinnings) also have been studied in the even-aged stands. An experiment in precommercial thinning was initiated in a two-stage shelterwood compartment approximately 10 years after overstory removal (Brissette et al. 1999). Analysis 18 years after treatment revealed that early thinning to an 8- by 8-foot spacing resulted in greater diameter and height growth and favorable shifts in species composition relative to no thinning. In a related study, trees precommercially thinned to a spacing of about 6.5 by 10 feet could be commercially thinned 20 years after treatment, while most of the trees in the unthinned portions of the stand still were of sapling size. Phillips (2002) reported significant differences in stem form between thinned and unthinned trees, concluding that precommercial thinning affected the accuracy of a commonly used volume equation for red spruce (Honer 1967). Phillips found that Honer's (1967) equation overestimated the volumes of large poletimber (8 to 10 inches dbh) red spruce in precommercially thinned stands, likely due to the greater stem taper of those trees.

In the selection stands, analysis of structural development over time revealed that the diameter distributions have moved farther from, rather than closer to, the defined target with repeated entries at all cutting cycles. As an example, see the findings for a stand managed on a 5-year cutting cycle in Seymour and Kenefic (1998). Analysis of age structure revealed both weak age-size relationships and a paucity of spruce trees < 100 years old at breast height in stands managed under 5- and 10-year cutting cycles. Similar data collected in stands cut every 20 years will soon be analyzed. Preliminary findings suggest that an unbalanced age structure and slow rates of sapling ingrowth contributed to the development of a bimodal rather than reverse J structure. In fact, when a class of sapling ingrowth was followed from the 1970s to the present, it was found that only 2 percent had reached merchantable size and that more than 80 percent had died (there were no significant differences between selection treatments) (Kenefic and Brisette 2005). This is particularly troubling since leaf-area research established that potential growth efficiency declines with age for these species (Seymour and Kenefic 2002), and that the amount of light typically available in the understories of the selection stands provides fir and hemlock with a competitive advantage over the more desirable spruce (Moores 2003). These findings have brought into question the long-term sustainability of northern conifer selection stands under current treatment goals, and has spurred additional research into the dynamics of ingrowth to merchantable-size classes.

The PEF experiment also has generated important findings with respect to fixed diameter-limit cutting. Though generally recognized as an exploitative practice, data on the long-term impacts of diameter-limit removals are rare. One of the few long-term studies of diameter-limit cutting was initiated on the PEF. Because the harvest interval (20 years) coincides with that of one of the selection-cutting variants, we were able to compare the effects of these two practices when applied in a single forest to stands with similar initial conditions. Although harvest revenues were greater, fixed diameter-limit cutting resulted in less sawtimber growth and volume, less regeneration, more unmerchantable volume, and a lower residual stand value after three treatments (40 years of study) (Kenefic et al. 2005). Hawley et al. (2005) reported significant differences in genetic diversity of residual hemlock trees in the selection and fixed diameter-limit stands, concluding that short-term fitness had been reduced by diameter-limit cutting due to a greater number of rare, deleterious alleles. These studies revealed that short-term financial benefits are offset by long-term degradation and should be of great interest to both practitioners and policymakers. Additional analysis of diameter-limit alternatives, including modified diameter-limit cutting and commercial clearcutting, is underway. Preliminary results suggest that fixed diameter-limit stands are more similar to commercial clearcuts than other multi-aged stands, and that there may be few differences between modified diameter-limit and selection cutting (Kenefic et al. 2004).

Considerations

Ostrom and Heiberg (1954) reviewed the advantages and disadvantages of large-scale silvicultural tests in the Journal of Forestry shortly after the PEF study was initiated. The advantages they cited, mostly associated with the practical aspects of area-control regeneration methods such as group selection, harvesting operations, and the study of stand-level dynamics, remain valid today. The need for suitable area in which to study wildlife population response to treatment is another important factor, and one that might not be met even by stand-level experiments. The disadvantages of large-scale experiments put forth by Ostrom and Heiberg (1954) include the need for abundant and consistent funding, and low or no replication. These are not minor considerations, and have challenged scientists on the PEF since the study's inception. Wakeley (Wakeley and Barnett, in press) offers an even dimmer view of large-scale silvicultural experiments. He describes compartment studies as "a generally inefficient means of silvicultural research. Their cost in labor, professional manpower, material…and regulatory wrangling is high. They yield immense quantities of highly variable data…." These criticisms raise the question: should research on the PEF be continued?

The answer is a resounding "yes." Unlike many early silvicultural studies, the PEF experiment includes replication, which enables us to draw conclusions even by today's rigorous statistical standards. Although low power is acknowledged as a challenge to establishing treatment effects, it is no longer a fatal flaw after publication of statistically significant findings in the 1990s and 2000s. Further, our ability to show treatments applied to stands averaging 25 acres in size, and to associate our findings with those areas strengthens the tie between our research and practical application. The large-scale study has allowed the investigation of phenomena such as canopy structure and habitat diversity as well as the economics of inventory, marking and harvesting. Large stands have been subdivided to allow the application of new treatments without jeopardizing the initial study, and have served as hosts to numerous short-term and small-scale studies by cooperating scientists who have neither the time nor the resources needed to establish desired stand structures or compositions. Most importantly, the 50-year history of treatment and measurement enables us to investigate questions about long-term forest sustainability and productivity that smaller scale and shorter-term studies could not answer.

Conclusion

The USDA Forest Service study on the PEF is one of the best examples of long-term silvicultural research in the region, and one of a few such installations in the country (see Adams et al. 2004). Consistent and meticulous application of treatments and collection of data make the PEF an invaluable source of research that informs land managers, landowners, and others. The highlights presented here showcase only a few of the studies on the PEF. Many other short-, medium-, and long-term research projects have been and are being conducted on topics such as seed viability (Frank and Safford 1970), regeneration (Brissette 1996), tree physiology (Day et al. 2001), insect diversity (Su and Woods 2001), stem form and quality (Philips 2002), rooting patterns (Tian and Ostrofsky 2002), sampling methodology for coarse woody material (Brissette et al. 2003), and snag longevity (Garber et al. 2005). Detailed data on forest change over a half century with specification of treatment history enable studies of newly important issues to have greater meaning than if done in stands without a history of measurement.

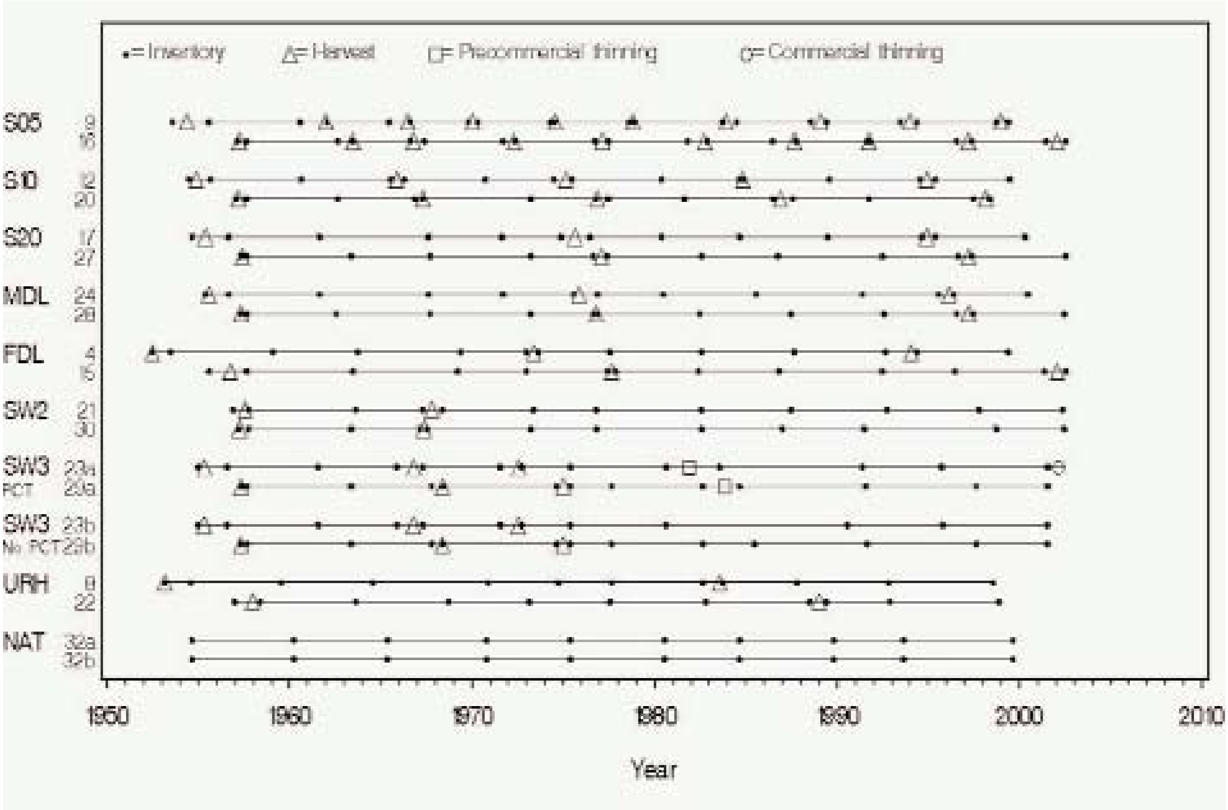

Figure 1: PEF Long-term Silviculture Study 1952 - 2002

Research conducted on the PEF is critical to answering questions about the effects of management on northern forest ecosystems. Although initial conditions were similar in all compartments, treatments have moved them along different pathways to profoundly different outcomes. It is imperative that the study be continued, both to answer the questions posed 50 years ago, and to address changing forest values and influences. Despite the fact that the PEF research has been conducted for more than a half century, we have discussed only a short period relative to the lifespan of the dominant tree species. Treatment responses are not yet fully realized and many questions remain unanswered. Perhaps more importantly, the data collected on the PEF provide a basis for generating and answering future questions. Results of interest to practitioners and policymakers already have emerged and the value of the PEF is increasing exponentially over time.

For additional information about the PEF, visit the Northeastern Research Station's PEF website at http://www.fs.fed.us/ne/newtown_square/research/experimental-forest/penobscot.html.

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