Long-term Forest Ecosystem Studies of the Cooperative Forestry Research Unit and the University of Maine

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Introduction

Since 1975, the University of Maine's Cooperative Forestry Research Unit (CFRU) has been helping landowners address some of the most important forest management problems facing the state. Now one of the oldest forest landowner/university research cooperatives in the country, the CFRU was originally formed to provide forest landowners with science-based solutions as they work to improve forest productivity and to protect forest ecosystems.

The CFRU was formed amongst landowners and University of Maine faculty members who were concerned about the short- and long-term implications of the extensive spruce budworm outbreak that dramatically influenced the Maine Woods during the 1970s. Forest landowners and researchers joined forces to better understand management and biological impacts on Maine's forest. A partnership was conceived that over the next 30 years developed into a comprehensive research program addressing everything from wood supply to the impacts of forest management on wildlife habitat, water quality, and biodiversity.

Together, its 25 current member organizations, representing private and public forest management organizations across the state, guide and support research on key forest management issues facing Maine's forests. CFRU activities are funded by financial and in-kind contributions from its members. Over the last 30 years, the CFRU has been able to adapt to the dynamic condition of Maine's natural resources and the changing needs of landowners. As a cornerstone for immediate and long-term research needs, the CFRU continues to develop as new paradigms challenge our existing knowledge and technology. The CFRU's mission is to conduct applied scientific research that contributes to the sustainable management of Maine's forest for desired products, services, and conditions.

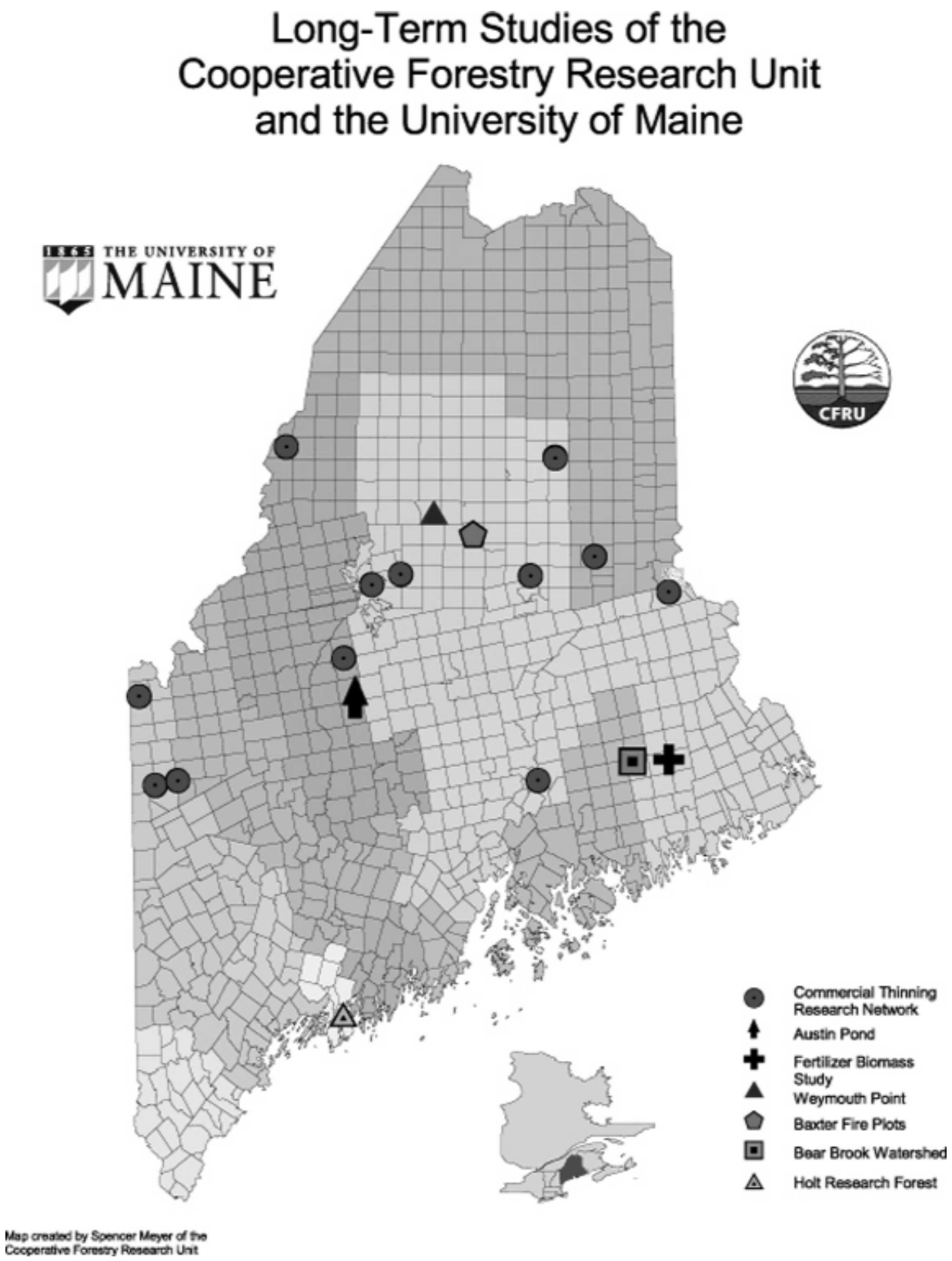

Figure 1. Long-term forest research studies of the CFRU and the University of Maine span much of the Maine Woods.

Austin Pond

The Austin Pond Study is the CFRU's longest running research site and has provided one of the best opportunities to document the long-term effects of herbicide treatments and pre-commercial thinning (PCT) on spruce-fir stands in the region. The study was established in 1977 by Max McCormack and the CFRU and originally included 12 aerially sprayed herbicide treatments and untreated control plots (1981 CFRU Annual Report) (Figure 2). In 1986 after some of the original research questions had evolved to reflect the results of the first series of measurements, the original herbicide plots were subdivided and half of each plot was PCT'd to study the effects of density management on growth and yield.

In 1999, the Austin Pond Study was revisited 22 years after the herbicide treatments and 13 years after the thinning treatments to examine the long-term effects on the development of spruce-fir stands as the result of these management tools (Daggett 2003). The objective was to quantify the overstory composition and stand structure following the herbicide and PCT treatments. Plots were relocated, remarked, and mapped with a global positioning system (GPS), a technology that was not yet available at the time of the previous measurements. The Stand Visualization System (SVS), a graphical stand composition tool, has been used to compare the stand compositions that resulted from each treatment (Figure 3). Based on information about the changes in stand composition and structure gleaned from this study, a growth model was used to forecast future growth and financial returns. As the study continues to be monitored, this long-term dataset will contribute to the further development of forest growth models.

Future stand development of all plots also was projected using FVS-TWIGS and the rotation-long financial returns associated with herbicide and PCT treatments calculated. The net present value (NPV) using a 4% discount rate at stand age of 50 years was $627 /A for the glyphosate and triclopyr herbicide treatments, $541 /A for the phenoxy herbicide treatments, and $414 /A for the untreated control. The NPV for

Figure 2. Treatment effects are apparent one year after herbicide treatment at Austin Pond.

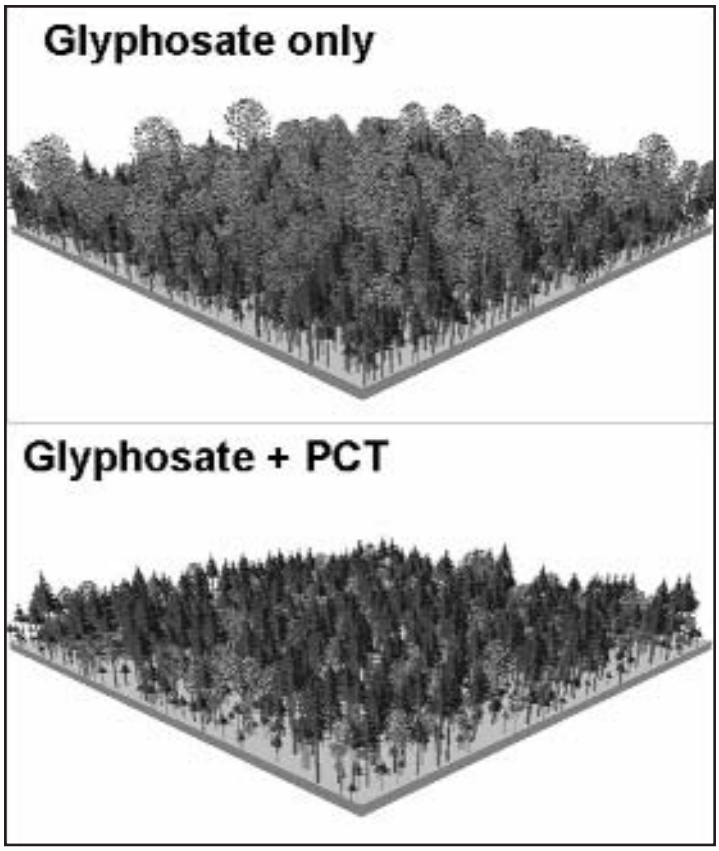

Figure 3. Stand Visualization System (SVS) representations of Austin Pond herbicide treatments show differences in species composition.

PCT alone was $360 /A. Herbicide + PCT treatments had NPVs around $290 /A. Mean internal rates of return were about 8% for herbicide treatment alone, 6.1% for PCT alone, and 5.8% for herbicide + PCT.

Results from the most recent study of Austin Pond offer several new insights about the long-term effects of intensive management on stand development. Although total wood volumes (with hardwoods included) were not increased by herbicide or PCT treatments 22 and 13 years after treatment, respectively, the proportion of wood volume in softwood (balsam fir and red spruce) at 29 years was substantially increased by herbicide and PCT treatments. Among 14 herbicide treatments tested, softwood composition was 74% in herbicide-only plots, 88% in PCT-only plots, and 92% in herbicide + PCT plots, while the untreated control plots had only 23% of the volume in softwood. The influence of herbicide and PCT treatments on the merchantable volume of softwoods was compared using several standards. Using the lowest standard (i.e., using the smallest merchantable top diameters), softwood volume was increased by 171% in herbicide-only plots relative to untreated plots. When including only the newer herbicides (glyphosate and triclopyr), merchantable softwood volume increased 264% above untreated plots. Results also indicated that the effect of herbicides was enhanced further if the stands were later subjected to PCT. Previous herbicide application also enhanced the later effectiveness of PCT. When herbicides and PCT were used in combination, merchantable softwood volume was 411% greater and total financial value more than two-fold higher than the untreated controls at 29 years.

Detailed information about the Austin Pond analysis can be found in a thesis by Daggett (2003) at http://www.umaine.edu/cfru/.

Weymouth Point

Since 1979, the CFRU's Weymouth Point paired watershed study has been an ideal experiment to ask a number of questions about the effects of silvicultural practices. Prompted by concerns that whole-tree harvesting techniques resulting from clearcut prescriptions might reduce nutrient availability, an experiment was implemented at Weymouth Point on the eastern shore of Chesuncook Lake. One of only three watershed studies in Maine (along with the Bear Brook Watershed Study and the Howland Forest), the Weymouth Point study is particularly valuable for its large-scale design that accommodates the study of ecosystem-level processes.

Year	Activity
1979	Study initiated with bi-monthly stream water sampling
1980	Atmospheric deposition chemistry (wet + dry) initiated Road right of way construction Installation of ceramic cup tension lysimeters 25 and 50 cm below soil surface (12 plots on treated, 4 plots on control)
1981	Mechanical harvest of treatment watershed started Mechanical harvest completed, hand crews began Hand crew harvest completed Soil disturbance transects established in adjacent 97 ha stand
1982	Planting plot I
1983	First site maintenance agreement written between Cooperative Forestry Research Unit and the landowner
1984	Adjacent 97 ha spruce-fir stand whole-tree harvested
1985	Conifer release by aerial triclopyr application (2 kg ae/ha)
1986	Planting plot II Atmospheric deposition chemistry monitoring discontinued Soil disturbance transects established in adjacent 97 ha stand Laboratory incubation for N mineralization initiated Triclopyr residue sampling completed
1988	Stream water monitoring discontinued
1991	Establishment of 27 plots (10m X 10m) in dense conifer regeneration across soil drainage classes Lysimeter installation (25 & 50 cm below mineral soil surface) Begin monitoring air temperature and rainfall Begin pre-PCT inventory Begin sampling stream water, soil solution and ground water Drill 7 wells into basal till to monitor ground water chemistry Application of PCT treatment (1.8m X 1.8m nominal spacing)
1992	Measurement of crop tree dbh and total height
1993	Collect foliage samples for laboratory analyses Fertilizer application (100 kg N/ha as ammonium nitrate) to PCT plots Second fertilizer application (100 kg N/ha as ammonium nitrate) Collection of foliage for laboratory analysis Litter trap installation First litter trap sampling Second litter trap sampling Third litter trap sampling
1994	Measurement of crop tree dbh and total height Collection of foliage for nutrient analysis
1997	New PCT plots installed for stream and soil element concentration study New lysimeters installed
2005	Long-term site maintenance agreement renewed with Katahdin Forest Management

Table 1. The Weymouth Point study has hosted myriad research opportunities during its 25 years.

In 1981, after two years of baseline monitoring, one of the two watersheds was clearcut with whole-tree harvesting techniques (Briggs et al. 2000). Subsequent measurements monitored the initial removal and soil flux of nitrogen, phosphorus, calcium and magnesium. The treated watershed was allowed to regenerate naturally and in 1984, the dense regenerating stand was treated with herbicide to release the desired conifer species from the competitive hardwoods and shrubs. The soil and stream nutrient dynamics continued to be remeasured. Then in 1998, the two watersheds were split and components of each were treated with precommercial thinning (PCT).

The paired watershed, where nutrients in the vegetation, soil solution, and stream water have been intensively monitored since 1979, continue to provide a unique opportunity for addressing questions about the influence of silviculture on nutrient dynamics. The numerous studies that have occurred on the site provide a strong foundation for long-term research of our forest ecosystems (Table 1). Weymouth Point data show that intensive management does not affect nutrient cycling for a long period of time. We now know that sites similar to Weymouth Point can support this type of harvesting and vegetation control without compromising the ecosystem (Briggs et al. 2000).

In cooperation with the landowner, Katahdin Forest Management, LLC, the CFRU continues to maintain the long-term integrity of the Weymouth Point site. Though ownership changes often threaten the integrity of long-term research studies, the cooperative nature of the CFRU has proven vital to preserving research investments. As the watersheds continue the progression through the stages of stand development, further opportunities for nutrient dynamics, silviculture and biodiversity research will present themselves.

Commercial Thinning Research Network

The vast acreage of dense spruce-fir stands that resulted from spruce budworm infestation, salvage cutting, and early stand management (herbicide and PCT) have matured and provide a new opportunity for forest management in the state. The substantial increase in partial harvesting of the Maine forest that resulted from changes in the Forest Practices Act in 1990 has brought greater attention to commercial thinning for stand improvement and gaining early financial returns from long-term silvicultural investments. Scientists from CFRU worked with other University of Maine researchers to organize the Thinning in Maine Conference in 1999 to address growing concerns over the lack of information available to land managers about commercial thinning Maine forests. The result of that conference and other work was the CFRU's Commercial Thinning Research Network (CTRN).

Funded by CFRU and implemented in 2000, the CTRN currently includes two experiments in spruce-fir stands on a dozen sites across the state of Maine (Figure 1) (Wagner and Seymour 2005). The network currently consists of two controlled studies examining commercial thinning responses in Maine's spruce-fir stands. The first study was established in mature balsam fir stands on six sites that had previously received precommercial thinning (PCT) to quantify the growth and yield responses from timing of first commercial thinning (year 1, year 6, and year 11) and level of residual relative density (33% and 50% relative density reduction). The second study, also established on six sites, was installed in mature spruce-fir stands without previous PCT to quantify the growth and yield response from commercial thinning method (low, crown, and dominant) and level of residual relative density (33% and 50% relative density reduction). Seven 0.20-acre measurement plots centered within one-acre treatment plots were established on each site. More than 12,000 trees are being monitored annually across the 12 sites.

A variety of other studies have been superimposed on CTRN sites (see 2005 CFRU Annual Report). Data from the CTRN are being used to address short-term questions as well as provide data for improving the ability of regional growth and yield models to predict stand responses to commercial thinning.

Holt Research Forest

The Holt Research Forest (HRF) is a 120 hectare (300 acre) forest located in Arrowsic, Maine where a research team from the University of Maine has conducted a long-term forest ecosystem study since 1983. HRF is the result of the Holt family's vision to support long-term forest ecosystem research in Maine. In 1981, the Holts established the Holt Woodlands Research Foundation, and partnered with the University of Maine to establish a research station and program (The Holt Research Forest 2005). A research and management plan, based on objectives similar to those of a non-industrial private landowner has driven the project. The Holt Research Forest was one of the first research efforts in Maine to incorporate ecosystem science and forest management.

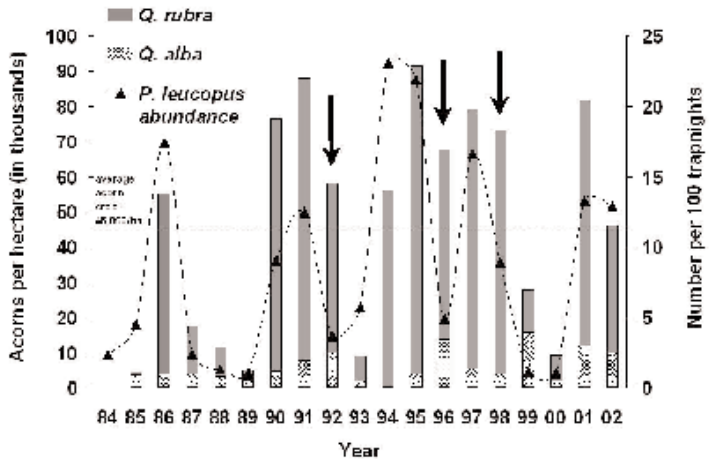

Figure 4. Changes in white-footed mice abundance at HRF as it relates to acorn production. This time series shows a statistically significant relationship. The value of a long-term data set is demonstrated here. If studying the short-term impacts of harvesting (1 year pre and 2 years post), imagine the different conclusions that might be reached for studies beginning in 1989 vs. 1998.

Arrowsic is an island surrounded by the Kennebec River to the west and south and the Sasanoa and Back Rivers to the north and east, located 10 km from the ocean. The soils are derived from shallow glacial deposits on ridges and deep glaciomarine sediments in low-lying areas. The forest is predominantly a dry ridge, pine oak ecosystem typical of mid-coast Maine, which falls within the transition between the oak-pine forest to the west and south and the spruce-fir forest to the east and north. Dominant tree species are white pine, red maple, and red oak with strong components of red spruce, hemlock and white oak.

Long-term and baseline data sets that have been created include the following: Cover-type map, high-intensity soils map, 100% timber inventory (3 replications), all trees numbered, 20 ha mapped trees, mapped canopy gaps, tree height, age, crown, and volume measurements, tree regeneration, vegetation abundance and distribution, small mammal populations, bird territories, salamanders, nest predation, fruit production, insect frass, plant phenology, plant reproductive effort and others. This baseline of data allows for easy integration with additional studies and provides a wealth of information for evaluating ecosystem changes over time.

Research being conducted on the Holt Forest will contribute significantly to quantifying the ecosystem effects of low-impact timber harvesting. The forestry practiced at the Holt Forest works with native forest

composition, structure, and processes. It maintains a natural distribution of age classes and species, while producing useful benefits to people. This type of forestry practice meets both private and public goals for forest management, demonstrating that economic and ecological productivity do not have to be in opposition.

The long-term data sets have allowed us to study population changes resulting from spatial changes (a timber harvest) against a backdrop of changes over time. Starting in 1983, we collected five years of baseline data on the 40-ha study area. In the winter of 1987-88, we performed a selective harvest (40% basal area removal) on ten randomly selected, 1-ha blocks on the 20-ha "managed" side. From 1988 to present we have collected post-harvest data from both the "managed" and unharvested, "control" sides. Research on the HRF is important because continuous, long-term data sets in ecology are rare and unusually valuable (Figure 4). Most ecological research operates in time scales of 2-5 years, driven by cycles of funding and graduate projects, while ecological processes often occur over decades. Uncertain funding and/or changing personnel frequently undermine projects designed to be long-term. The HRF is the only operating oak-pine research forest in Maine and it is one of only two forests (with the Harvard Forest) dedicated to oak-pine research in the Northeast. Though the oak and pine forest types represent only 10% of Maine's forestland, over 80% of the forest cover in Maine's southern counties is oak pine types and it is responsible for a significant portion of Maine's total forest economy.

Bear Brook Watershed

The Bear Brook Watershed in Maine (BBWM) is a long-term, paired watershed study originally designed to evaluate the effects of elevated atmospheric N and S deposition on a small, forested ecosystem in northern New England. The study, initiated in 1986, combines long-term measurements of chemical and hydrological budgets in a reference watershed (East Bear) with experimental additions to an adjacent treated watershed (West Bear) (Bear Brook Watershed 2005). West Bear treatments were initiated in 1989 and continue as aerial applications of $(NH_4)2SO_4$, equaling 28.8 and 25.2 kg ha-1 yr-1 of S and N, respectively. This design allows for the evaluation of forest ecosystem response to ambient levels of N and S deposition in a changing chemical and physical climate. The BBWM program began as an experiment focused on S induced stream acidification and evolved to a comprehensive ecosystem program of research studying whole-ecosystem acidification processes, N saturation, base cation depletion, metal mobilization, alterations in P cycling, C sequestration, and climate change.

BBWM is located in eastern Maine at 44°52' N. lat. and 68°06' W. long., 40 km inland from the Gulf of Maine. The watersheds occupy the upper 210 m of the southeast slope of Lead Mountain (elev. 475 m). Two nearly perennial, low DOC, low ANC streams drain the 10.3 and 11.0 ha watersheds. Soils are coarse, loamy till averaging 0.9 m in thickness and generally freely-drained throughout the watersheds. The bedrock is quartzite and meta-pelite, intruded by granite. Monitoring includes studies of solution chemistry and volume (precipitation, throughfall, stemflow, soil solutions, groundwater, and streams), biology (forest growth and composition, root dynamics, microbial processes, macroinvertebrates), and soils. Numerous one-time experiments and data sets have been developed.

Forests in both watersheds are similarly distributed in three cover types—hardwoods, mixedwoods and softwoods. The five dominant tree species are *Fagus grandifolia* (American beech), *Acer rubrum* (red maple), *Acer saccharum* (sugar maple), *Betula alleghaniensis* (yellow birch), and *Picea rubens* (red spruce). Detailed vege-

tation studies began in 1993. Studies were designed to assess the effect of acidification and initially concentrated on over-story trees. Forest responses evaluated included foliar chemistry of hardwoods and red spruce, nutrient resorption dynamics of hardwoods, wood production and relative density in red spruce and frost hardiness in red spruce. Detailed growth analyses on tree rings in 1998 showed the first measurable response to the increased ammonium sulfate treatment. Studies followed on photosynthetic and transpiration rates of dominant over-story trees and effects of increased ammonium sulfate on spruce seedling growth. Other vegetation studies covered bryophyte communities, and non-woody forest floor vegetation. A complete forest vegetation inventory was established and archived in 2000.

Regional and global-scale changes in the physical and chemical environment underscore the need for high-quality long-term ecosystem-scale studies conducted at a range of sites or 'observatories'. These types of studies are essential to (i) understand and evaluate short- and long-term fluctuations in atmospheric chemistry and climate and subsequent effects on ecosystems, (ii) provide data to improve and validate local, regional, or global-scale models to better predict or anticipate future trends, and (iii) identify ecological 'surprises' or threshold effects that might not be anticipated based on current theory and short-term observations. The results of research at BBWM have verified models of ecosystem acidification as well as revealed processes and responses that are not fully understood, and that change in their character as the research moves from short-term (years) to longer (decadal) timeframes. Without the sustained commitment to the program of research at BBWM, it would not have been possible to evaluate these responses. Soil chemistry, stream chemistry, root dynamics, microbial processes, and forest growth all have shown responses that were different in character after 10-15 years of treatment compared to the initial 2-3 year responses.

Nitrogen Fertilization Studies

The objective of this ongoing project is to evaluate whether nitrogen (N) fertilization following precommercial thinning (PCT) increases the productivity of spruce-fir stands. In late 2003, two CFRU fertilization studies (Weymouth Point and T30-31) established in the mid 1990s were remeasured. This pair of studies provides a unique opportunity to examine the effect of N fertilization two years after PCT or about eight years after PCT when the stands are near crown closure.

Both study sites were clearcut harvested in 1981, naturally regenerated to balsam fir and red spruce and then released in the mid-1980s from shrub and hardwood competition using aerially-applied herbicides. Around 1991, both sites were PCT to about 1,200 trees per acre. At the Weymouth Point site, 178 lbs/A of N fertilizer was applied two years after PCT to experimental plots that were replicated and blocked by soil drainage. At the T30-31 site, experimental plots were aerially fertilized with 178 lbs/A of N fertilizer about eight years after PCT when the stands were near crown closure. In fall 2003, all trees in the untreated controls and treated plots were remeasured to provide the volume growth 12 years after PCT and 10 years after N fertilization at Weymouth Point, as well as about 12 years after PCT and six years after N fertilization at the T30-31 site.

Our analysis indicates that fertilization increased wood volume growth in the T30-31 study but not in the Weymouth Point study. Mean stand volume growth across soil types was only 0.2 cords/A/yr higher in the fertilized than unfertilized plots in the Weymouth Point study. In contrast, results from the T30-31 study indicated that individual balsam fir had 82% higher volume growth in fertilized than unfertilized plots. When scaled up to the stand level, results from the T30-31 study suggested a mean increase in volume growth of

49% or about 1 cord/A/yr from fertilizing PCT stands near crown closure. Although there are clearly differences in the experimental design and sites between the Weymouth Point and T30-31 studies, these results suggest that volume production gains from N fertilization may only occur when spruce-fir stands have received PCT and followed later by N fertilization just before crown closure (as in the T30-31 study). The higher yield and delayed fertilization in the T30-31 study produced a net present value (NPV) of $60.13/A (7% discount rate) and an internal rate of return (IRR) of 12.2% while the Weymouth Point Study produced a NPV of $-62.72 /A (7% discount rate) and an IRR of 1.3%. Thus, results from these studies clearly indicate that N fertilization of PCT spruce-fir stands that are near canopy closure and on well-drained sites deserve a closer look.

Baxter State Park Fire Plots

In July 1977, 1,439 hectares in and adjacent to Baxter State Park experienced a severe forest fire. Much of the fire burned through areas that were blown down in a 1974 windstorm; some of those areas were salvage logged prior to the fire, while others were not. In 1978, Sandra Hansen set up 60 permanent plots representing six distinct disturbance histories, measuring vegetation composition and structure. One year after the fire, vegetation on burned sites was dominated by bristly sarsaparilla, pin cherry, poplar, and birch. Overall, Hansen concluded that fire affects re-vegetation patterns and that re-sampling the plots would contribute to understanding forest development in Acadian spruce-fir ecosystems.

In 2003, 25 years after initial establishment, the Baxter Fire Plots were re-located and re-measured. Most of Hansen's measurement techniques were repeated; however, tree and coarse woody debris data collection was intensified to reflect changes in stand structure. Burned sites are now dominated by white birch and poplar. Pin cherry accounts for much of the standing dead wood suggesting that it was an important part of the tree canopy in the previous two decades. Bristly sarsaparilla, the dominant vegetation immediately after the fire, is now difficult to find. The variability of tree species developing within the burned stands suggests that future developmental dynamics may result in diverging overstory conditions. Baxter Fire Plot coordinates were obtained and rebar stakes were topped with plastic identifying caps to facilitate future re-location and re-measurement.

Chemical Strip-Thin Experiment

In the early 1980s, in response to the so-called "doghair" spruce and fir thickets resulting from the spruce budworm of the 1970s, the CFRU initiated research to develop a cost-effective way to reduce overstocking and increase stand productivity. By using helicopters with specially designed herbicide application booms, it became possible to quickly and inexpensively thin large areas. By using the boom with nozzles spaced accordingly, strips of herbicide can be applied to create regularly spaced rows of desired species. Herbicides that will control the desired species are delivered in a precise pattern to release those trees in the alternating strips.

Recently, there has been renewed interest in precommercially thinning stands using aerial herbicide applications. With spatially explicit aircraft guidance systems and improved herbicide spraying technologies, the prospect of inexpensive thinning is attractive. The CFRU chemical strip-thin plots will provide the framework for evaluating the efficacy and financial feasibility of this type of thinning. The application of such experimental treatments is the first step towards harvesting results from long-term silvicultural research.

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For more information about the CFRU see (http://www.umaine.edu/cfru) or contact the Research and Communications Coordinator, Spencer Meyer (spencer_meyer@umenfa.maine.edu).