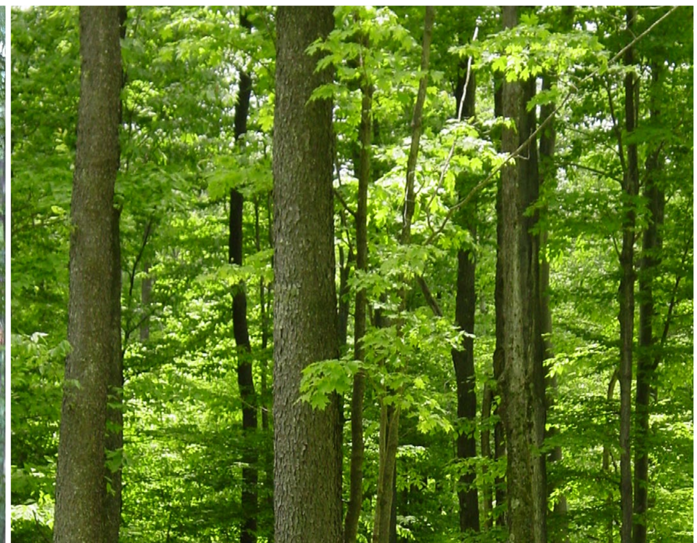
United States Department of Agriculture

SILVAH:
50 Years of Science-Management Cooperation

Proceedings of the Allegheny Society of American Foresters Training Session



Forest Service Northern Research Station General Technical Report NRS-P-186 September 2019

Abstract

This report represents proceedings of the Allegheny Society of American Foresters training session titled “SILVAH: 50 Years of Science Management Cooperation.” This meeting celebrated a unique and long-lasting community of practice that includes forest and natural resource managers and scientists. SILVAH originated in northwestern Pennsylvania in the late 1960s. Over time, the research results, shared efforts, and training sessions led to decision support software and all became known as SILVAH, and the geographic range of the community expanded. This published proceedings includes 12 papers that describe the origins and early history of the community of practice, the current state of science and management guidelines as presented at the conference, as well as a paper that explores the factors that contributed to its long-term success.

Cover Photos

Left: Photo from a research plot in 2008 near Little Arnot Creek. The area has been studied by the SILVAH community of practice since its origin in 1928. Photo by Ernie Wiltsie, USDA Forest Service.

Top right: Allegheny hardwood stand highlighting the relative importance of black cherry as well as the complex stand structure found in even-aged Allegheny hardwood stands as a consequence of the differing growth rates of the species typically found in this forest type. Photo by Barbara McGuinness, USDA Forest Service.

Bottom right: Fall color on the Kane Experimental Forest near Kane, PA. This Experimental Forest is one key site for SILVAH training sessions and research. Photo by Harry Steele, USDA Forest Service.

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SILVAH: 50 Years of Science-Management Cooperation

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INTRODUCTION

Susan L. Stout[1]

The Society of American Foresters Allegheny Section Summer 2017 training session was a celebration of a remarkably productive partnership. Beginning in the late 1960s, possibly at an Allegheny Section Society of American Foresters meeting, forest and natural resource managers in northwestern Pennsylvania worked with the USDA Forest Service to support and collaborate on a rigorous and challenging research agenda. The partnership began because the region was experiencing a crisis in natural regeneration, and over the decades it expanded to include several other lines of science. Many of these were represented by presentations at the September 2017 meeting. Many presentations combined an historical overview of scientific work, its translation into management guidelines, and its adoption by managers. In several key cases, presenters went on to describe how managers were able to use research results to bring key policy changes, such as changes in the management of an historically overabundant deer herd, Pennsylvania-wide assessments of regeneration adequacy, or a cohesive multi-agency collaboration to sustain oak in southeastern Ohio. Many presentations ended with a summary of the current state of science and implications for forest management.

During the course of the partnership that is celebrated in this proceedings, scientists began to share research results with managers by way of annual training sessions. These sessions described the results of research in a way that helped managers see how to adapt their management practice to take the results into account. This included suggestions for new ways to collect forest inventory data in stands where management was planned, and to use these data to determine a course of silvicultural treatments. As the training sessions continued, scientists developed a computerized decision support system into which managers could enter inventory data and receive both a comprehensive summary of current conditions and recommendations for the course of silvicultural treatments. The name SILVAH, originally an acronym for Silviculture of Allegheny Hardwoods, was first applied to the decision support software. Over time, SILVAH became an umbrella term for the science-management partnership and the various lines of science needed to support sustainable forest management, and eventually was extended to include mixed oak forests.

The work celebrated at the training session is truly collaborative work by hundreds of managers, scientists, interns, and stakeholders over the five decades since its inception in the late 1960s. We especially want to acknowledge the contribution of the permanent employees of the USDA Forestry Sciences Laboratories in Irvine, PA, and Delaware, OH, during this period. In particular, we acknowledge the commitment and dedication of those who installed the research studies and collected research data with precision, entered data, or wrote code for decision support software. They appreciated, every day, that the quality of their work could make the difference between detecting a meaningful difference among treatments or not, or a program that was useful or not. Led by Virgil Flick, Harry Steele, and Ernie Wiltsie, the technician crew also included Eric Baxter, Von Brown, Bill Borovicka, Carl Bylin, John Crossley, Reid Garrison, Josh Hanson, Joan Joliff, Pete Knopp, Lance Meyen, Linda Ordiway, Todd Ristau, Dave Saf, Greg Sanford, Julie Smithbauer, Scott Thomasma, and Corinne Weldon. We also acknowledge the contributions of the scientists in that period who designed studies, consulted with managers and technicians, analyzed data, developed guidelines, and reported results. Led by Dave Marquis, and Ben Roach, the scientists also included Lew Auchmoody, John Bjorkbom, Patrick Brose, Dave deCalesta, Rich Ernst, Kurt Gottschalk, Coeli Hoover, Steve Horsley, Bob Long, Gary Miller, Chris Nowak, Joanne Rebbeck, Todd Ristau, Scott Stoleson, and Susan Stout.

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Without the help of Penn State University Extension, a Forest Service Environmental Educator, and leaders in other states, the SILVAH community of practice would not have been possible. Led by Sandy Cochran, these invaluable partners included Dave Apsley, Kimberly Bohn, Wade Dorsey, Barbara McGuinness, Tim Pierson, Kathy Smith, Scott Weikert, and Sarah Wurzbacher. The SILVAH:Oak sessions also depended on our partnership with the Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry, especially the Clear Creek State Forest.

Finally, forest management organizations across the Plateau have contributed everything from in-kind labor through study sites and treatments to financial support. Although many have participated, SILVAH has had long-term partnerships with the Allegheny National Forest, Collins-Kane Hardwoods, Forest Investment Associates, Generations Forestry, Hammermill Paper Company, International Paper Company, Keith Horn, Inc., the Pennsylvania Bureau of Forestry, and the Pennsylvania Game Commission. In Ohio, the Ohio Department of Natural Resources Division of Forestry and Division of Wildlife and the Wayne National Forest played important roles.

THE EARLY YEARS OF SILVAH

David A. Marquis[1]

INTRODUCTION

I was delighted to learn that this meeting would focus on SILVAH, and that SILVAH is still being used and improved as a tool in the management of Allegheny hardwood and oak forests.

My task today is to tell you a little about the early years of SILVAH and some of the events that led to its development. The computer program we call SILVAH was preceded by many years of research into four main factors that affect the outcomes of silvicultural treatments in Allegheny hardwood forests.

- The role of well-developed advance reproduction for ensuring regeneration success.
- The impacts of protracted browsing by white-tailed deer.
- Effects of interfering plants such as ferns and understory beech on regeneration survival and development.
- Better ways to assess stand conditions and prescribe appropriate silvicultural treatments. This involved assimilating the findings from the research into silvicultural guidelines and then into a system of stand inventory, analysis, and prescription writing. That system was originally used without the benefit of computers.

Research That Led to SILVAH

The story begins with a regeneration problem that appeared with the shift during the 1950s and 1960s from a regionwide emphasis on uneven-age management to even-age management in most eastern hardwood types. It worked fairly well in many forest types. Adequate advance reproduction, good seed sources, and other factors generally resulted in satisfactory natural regeneration after clearcutting. But this was not so everywhere. Less-than-satisfactory species composition and outright regeneration failures occurred in some situations. These failures were severe and widespread in the Allegheny hardwood type.

The Northeastern Forest Experiment Station earlier recognized the regeneration problem in the Alleghenies and the need for research. This resulted in the construction of the Forestry Sciences Laboratory in Warren, PA, in the early 1960s. Warren Doolittle, the assistant station director in charge of silvicultural research, moved a few people from other locations to Warren, but lack of funding prevented any significant impact.

A late 1960s Society of American Foresters meeting publicized this problem and focused public attention on the need for additional research in this forest type. That meeting galvanized forest landowners to contact their representatives in the U.S. Congress. Norm Tuttle of Hammermill Paper Company and Art Bennett of Armstrong Forests led this charge for the forest industries. Tuttle was chairman of the Forest Resources Committee of the Pennsylvania Chamber of Commerce. He testified at appropriation hearings in Washington, D.C., about the need for expanded federal research into this problem.

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Supplemental funding bills for expanded research in northwestern Pennsylvania were introduced in Congress several times in 1968 and 1969 but did not pass. Then in late 1969, a supplementary appropriations bill passed with funds for the Warren research unit. I was appointed as research project leader, although I was at Yale working on a Ph.D. at the time. During 1970, I was able to design and install several large studies aimed at the Allegheny hardwood regeneration problem and use those studies to satisfy my dissertation requirements.

Over the next several years, we greatly expanded the research staff at the Warren Laboratory. Some were funded from the new appropriation, and some funding was transferred from other units. For most of the next 20 years, seven or eight scientists worked there, along with technicians and other support staff. The scientists included experts in silviculture, ecology, soil science, plant physiology, wildlife biology, and mensuration. We initiated a wide range of experiments aimed at all aspects of the regeneration problem and soon began to work in other areas of hardwood silviculture.

Research Planning

We found a lot of general information in the literature about the regeneration problem but not much that was specific and useful to a forest manager. For example, researchers generally agreed that most hardwood stands would regenerate satisfactorily if abundant natural regeneration occurred on the ground before cutting, and if only limited interfering plants such as ferns or beech root suckers grew. But the literature held no information about how much advance regeneration was enough or how many interfering plants were too many. Likewise, there was general knowledge that thinning would benefit yield in dense stands but no specific information on what density warranted treatment and no adequate method of evaluating relative stand density in Allegheny hardwoods stands with their wide range of species. So we created a decision chart that incorporated all the general information we had about the conditions that affect silvicultural treatments. Whatever specific information we could find on decision points was noted on early versions of the chart. Decision points for which data were inadequate or totally lacking became our priorities for research, and we added them as information became available. This approach worked very well, and we were soon able to develop guidelines and recommend practices. Our planning decision chart for research looked very similar to the final silvicultural decision chart that SILVAH uses.

Long-term Studies

We received a big boost from work that Ash Hough and others had started on the Kane Experimental Forest in the 1920s and 1930s. Although it was shut down during World War II and not reopened until the early 1960s, Hough had been transferred to Northeastern Forest Experiment Station headquarters, and he spent summers at Kane remeasuring those study plots at 5-year intervals into the 1960s. We picked up those studies in the 1970s, providing long, continuous records of stand growth and development of 40-60 years (including development of stands after clearcutting). That information greatly facilitated the early development of silvicultural recommendations for SILVAH.

Among the advances resulting from the availability of these long-term data were the development of a measure of relative stand density that accounted for differences in species composition, stocking guides for Allegheny hardwoods, and algorithms to predict stand growth. These advances greatly benefited the development of the SILVAH system.

Training Sessions

By 1976 we had enough information on both regeneration and thinning that we thought it important to distribute it to forest managers without waiting for a more complete version of SILVAH. We set up several 2-day information sessions at the Kane Experimental Forest where we could demonstrate how to apply the guidelines and understand their effects in real stands. Ben Roach, who was a researcher at the Warren Laboratory by that time, devoted 1 day to evaluation of stocking and thinning, and I devoted the second day to regeneration. The only place that was available to meet for the lecture portion of the training was the garage at the experimental forest. That venue lacked even the most basic audiovisual equipment. It did not even have a chalkboard, so we had to use chalk on the garage walls to present pertinent data. Each session was limited to 12 participants. At that time we still had significant gaps in our decision chart and had not yet assimilated our research findings into a prescription writing system.

Once we realized the strong interest in such training, we modified the house at the experimental forest to accommodate these sessions. We removed the partitions from the living room and dining room to create a larger and better-equipped meeting space. We were able to accommodate 18 people per session, and we expanded the sessions to 3 days to accommodate new research findings. During the next 5 or 6 years (1977 to 1984) we filled in many of the gaps in our decision chart and assimilated all the guidelines and recommendations into a coherent system, which we were then calling "A Stand Inventory, Analysis, and Prescription System for Allegheny Hardwoods." At that time the inventory data were still summarized manually, and prescriptions were determined directly from decision charts. There was no computer program yet, but the decision system that would become SILVAH was being widely used.

The training sessions remained popular, and forest management agencies from throughout the Allegheny region and beyond were regularly sending their foresters for training. We finally realized that we had created a monster, and that it was likely to continue for the foreseeable future. So in 1985 we built a new building at the experimental forest especially for these training sessions. It held 32 attendees, at tables, and was well furnished with audiovisual equipment and other amenities. Training sessions were extended to a full week to accommodate the constantly expanding guides that our research was developing.

We thought that nearly doubling the capacity of our meeting space would result in fewer weeks spent at this activity, but we still needed 3 weeks each year to accommodate those wanting to attend.

The SILVAH Computer Program

At about this same time, we wrote a Fortran computer program to use primarily in conjunction with the training sessions to do calculations from the class exercises. When personal computers began to appear in most workplaces, that program was expanded to handle the full stand analysis and prescription process, and we made it available to the public informally. It ran on an IBM two-floppy disk computer under DOS. The acronym SILVAH was used at that time to describe this computer program, but we intended SILVAH to refer also to the prescription system.

Testing of SILVAH

About 1980 we decided to compare the recommendations generated by the SILVAH program to prescriptions of experienced silviculturists. We arranged with Hammermill Paper Company to do such comparisons on a large compartment of its land where the company was about to perform thinnings and harvest cuttings in stands that were ready for such treatments. Hammermill collected the inventory data needed for SILVAH in all stands. Then, several of its most experienced prescribers would decide the appropriate treatment for each stand based on usual procedures. Finally, Hammermill ran SILVAH on each stand and compared the results of the two procedures. The results were identical in most cases. Where the results differed, the prescribers agreed that the SILVAH analysis had picked up something they missed, and they chose to adopt the SILVAH recommendations.

We made similar but less formal comparisons on both public and private forest lands, but with prescriptions written by less experienced prescribers. In these cases, SILVAH frequently provided information that the prescriber missed or gave prescriptions more appropriate to stand conditions or management goals than those of the less experienced prescribers.

SILVAH Publications

The first publication fully describing the Stand Inventory, Analysis and Prescription System for Allegheny Hardwoods, and citing the research background for those recommendations, appeared in 1984 (Marquis et al. 1984). It was revised in 1992 (Marquis et al. 1992). The first manual for use of the computer program SILVAH also appeared in 1992 (Marquis and Ernst 1992). A loose-leaf notebook containing all the lectures for the training courses, including all the slides, was published in 1994 (Marquis 1994). Then in 2014 the SILVAH User's Guide was updated with the latest information from the research and experience, and republished (Knopp and Stout 2014).

Stand Growth Simulator Added to SILVAH

By the time the first SILVAH manual was published, a stand growth simulator had been added to SILVAH, making it capable of suggesting prescriptions for silvicultural treatments in Allegheny hardwood and oak stands and allowing projections of stand conditions so users could compare potential outcomes from different treatments. This combination of capabilities in a single model was, and I believe still is, unique.

SUMMARY

The stand analysis and prescription system that form the basis of SILVAH benefited from:

- A well-funded research program and a great staff
- Research planning aimed specifically at providing silvicultural guidance
- Long-term studies installed in the 1920s-1930s and periodically remeasured
- Training sessions that explained the system, provided hands-on practice, and kept us aware of new problems and changing research needs

SILVAH will continue to evolve as managers face new challenges in managing their forests, and new information becomes available to address those concerns.

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FIFTY YEARS OF SCIENCE-MANAGEMENT COOPERATION FROM THE SILVAH COMMUNITY OF PRACTICE

Susan L. Stout, Patrick H. Brose, Helene Cleveland, Robert P. Long, Barbara McGuinness, Matthew P. Peters, Joanne Rebbeck, Todd Ristau, Alejandro A. Royo, Scott H. Stoleson, Scott Thomasma, Mark J. Twery, Sarah Wurzbacher[1]

Insights for Managers

- **Regular interactions between scientists and managers build a common vocabulary and framework that increase the efficiency of describing emerging problems and build shared ownership of the body of work.**
- **Managers improve applied research utility by directing a research program toward current management problems and by supporting (for example, through pilot studies) excellent work that attracts competitive funding.**
- **Collaboration between scientists and managers sharpens hypothesis formation by increasing the number and diversity of observations and perspectives on which hypotheses are based.**
- **Cooperation accelerates and diversifies site selection for designed experiments.**
- **Scientists can use their professional networks to engage colleagues from other regions with specialties not available locally, deepening the research and increasing its value.**
- **As managers participate they gain confidence in research results and become more willing to adopt new practices based on the research.**
- **Over time, a community founded on mutual respect emerges and scientists and managers coproduce both knowledge and improved practices.**
- **Continuity of participation and support by participating institutions—not just individuals—is critical to allowing research to detect answers that only emerge over the long term.**

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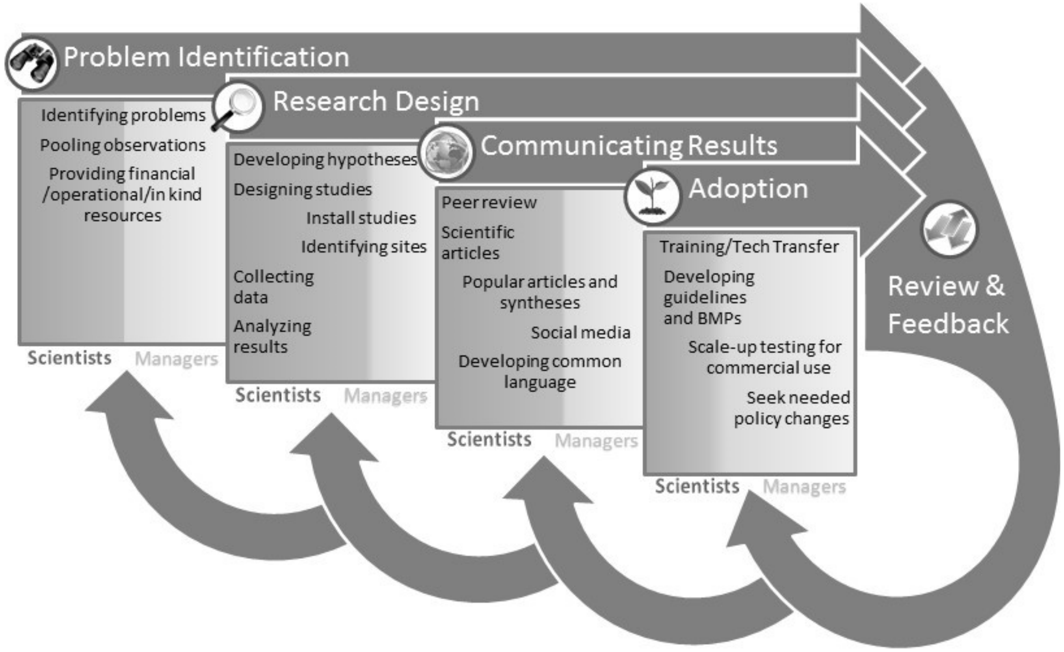

Figure 1.—Conceptual model of the SILVAH community of practice. Each step is shaded to indicate the approximate proportion of this work done by scientists (left, shaded portions of each rectangle) and managers (right, unshaded portions). The icons for each step are used to highlight examples in the text of the article.

INTRODUCTION

This chapter highlights patterns that have sustained a half century of science-management cooperation (Fig. 1) by summarizing the ways the community of practice functioned to support and benefit from seven lines of science during the last 50 years. Each demonstrates some or all of the common themes and patterns, and we use the icons from Figure 1 throughout the paper to draw attention to specific examples of mutual benefits:

 highlights cooperative work on problem identification.

 highlights work on research design.

 highlights work on communicating research results.

 highlights examples of adoption of research results.

 highlights interactive feedback between scientists and managers.

As Marquis (2019) outlines, managers have been SILVAH research partners since the beginning. The regeneration crisis in the High Allegheny Plateau region of Pennsylvania was first identified by managers who recognized that research would be an essential basis for a meaningful solution. They also recognized that merely understanding why so many final harvest cuts were failing was not enough; to sustain the region's forests, research results must lead to guidelines for new management practices.

For 50 years, forestry scientists and managers in the region became what is now called a "community of practice: a group of people who share a craft or a profession. It is through the process of sharing information and experiences with the group that members learn from each other, and have an opportunity to develop personally and professionally."[2] This community has conducted research and developed management guidelines related to many lines of science, and clear patterns have emerged (Fig. 1). The other chapters in this proceedings summarize some of the scientific progress the community has made over the last 50 years. This chapter highlights the underlying patterns of science management cooperation that have allowed this community of practice to flourish and grow.

SILVICULTURE AND DECISION SUPPORT

Managers played a key role in supporting the new research program; they were engaged from the beginning in pooling observations and developing hypotheses. The target was silvicultural strategies that would ensure successful regeneration. The research plan developed by David Marquis and the scientists on his team relied on a conceptual model: a highly accessible flow chart of hypothesized causes for regeneration problems, including soils, interfering plants, deer herbivory, and management practices, and corresponding studies designed to test these hypotheses. Managers often provided study sites or shared experiential insights about the various factors. Early results showed that deer formed a principal barrier and that sites with abundant advance regeneration were most likely to succeed. Additional research identified and tested shelterwood and herbicide practices to increase advance regeneration where absent.

Marquis and Ben Roach (who had been reassigned to the Warren, PA, office of USDA Forest Service Research and Development to participate in this exciting cooperative venture) coordinated with Sandy Cochran, the Penn State Extension forester in the region, to plan training sessions that were intended to show managers how to use guidelines and processes that were developed from the research. The structure of the training sessions was modeled on two preceding documents: the flow chart of factors that influence regeneration success and the "Silvicultural Guide for Upland Central Hardwoods" (Roach and Gingrich 1968). Both documents emphasized the link between data collected from individual stands and detailed silvicultural prescriptions. They also emphasized the relationships between factors ranging from the silvics of individual tree species to stand development patterns to biotic and abiotic influences.

The training sessions, first offered in 1976, attracted participants from public and private land management organizations and universities. It soon became apparent that the training sessions would play an important role in sustaining communication between scientists and managers. The quantitative, integrated framework, organized into decision charts, made these sessions different from usual workshops where individual talks might sometimes give contradictory suggestions, or where application of research results was not so tightly linked to an actual inventory procedure.

The silvicultural guidelines developed in the first decades of SILVAH research-management cooperation were eventually codified in a training session textbook (Marquis et al. 1992). A computer program, SILVAH (https://www.nrs.fs.fed.us/tools/silvah7/), processed stand data that were gathered using the inventory procedures taught in the training sessions and suggested a research-based, site-specific silvicultural prescription. These prescriptions included partial cuts for immature even-aged stands or stands to be managed in an uneven-age system and a variety of treatments to improve the probability of regeneration success in stands that had reached the conditions appropriate for replacement with a new, young stand.

[2] Wikipedia definition; accessed Sept. 11, 2017.

As described by Marquis (2019), the entire SILVAH process—inventory procedures, data analysis, and prescription development—were widely adopted by public and private land management agencies. One large industrial landowner, the Hammermill Paper Company, conducted a formal test of the process and found that it was consistently as good as or better than the processes it had been using before SILVAH.

As the strength of the systematic approach to inventory, analysis, and prescription became apparent, the Northeastern Forest Experiment Station created working groups to generalize the approach to other forest types and benefits such as wildlife habitat, hydrology, and forest aesthetics. The Stand Culture and Stand Regeneration working groups engaged many scientists across the station, in universities, and management partners. In 1990 the working groups traveled together across the northern Appalachians for a week to explore the potential of expanding the SILVAH idea. The working groups gave birth to a new decision support tool called NED (https://www.nrs.fs.fed.us/tools/ned/products/ned3/) (Twery 2019). SILVAH provides detailed silvicultural prescriptions for specific management objectives in individual stands; NED allows users to interpret these data from wildlife habitat, aesthetic, hydrologic, and other disciplinary perspectives, and to look at the combined attributes of neighboring stands. Data sets can be easily exchanged between SILVAH and NED to take advantage of the strengths of both programs.

When the training sessions were first offered, the organizers imagined that after a few years all managers in the region would have taken the course, and the sessions would be suspended. This vision was never realized: it became increasingly obvious that the integrated framework of the training sessions, combined with the community building aspects that resulted from scientists and managers spending time together and learning from each other, was fostering a culture of mutual respect and cooperation. As new research results emerged, they were placed in the SILVAH framework. Inconsistencies were resolved and shared with managers through the training sessions. The training sessions also became an important vehicle for managers to report emerging problems to scientists, and for management organizations to train new hires.

DEER-FOREST INTERACTIONS

Royo and Stout (2019) describe the scientific side of this line of science. For the entire five decades of this research, forest managers from public and private organizations have participated in refining hypotheses and defining the methods that would be used, especially when the research study involving deer enclosed in managed forests began in 1979 (Horsley et al. 2003). The Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry (DCNR BoF)[3], the Pennsylvania Game Commission, the Allegheny National Forest (ANF), and a private land management organization all contributed forest land to serve as study sites. Individuals from each organization and from the Society of American Foresters pitched in to install the experiment. This promoted a broad sense of ownership of the research and its results.

By 1985, the fifth year of the study, visitors could see—and the data confirmed—that differences between the enclosures clearly correlated with variation in deer densities. However, regeneration in the highest deer density areas was substantially better than anyone had anticipated. Again, managers and scientists gathered to brainstorm and conceptualized the idea that deer impact on vegetation is a joint function of deer density and forage availability. The emergence of this idea, which has increased in importance over the decades, depended

[3] This is the current organizational name of the Pennsylvania State Forestry agency. During the era of the deer enclosure study, it was part of the Department of Environmental Resources.

on engaging deer and land managers and silviculturists and wildlife biologists in the conversation. Specifically, one of the design features of the enclosure study was that within each deer density treatment 10 percent of the forest was clearcut and 30 percent was thinned to ensure comparable forage production in all areas. In contrast, managed forest land at the time averaged 4 percent and 13 percent in clearcut and thinned conditions, respectively. These differences in forage-producing habitat could explain the differences in impact that similar densities of deer had in the ambient forest compared to that inside the enclosures. Formal testing of this hypothesis was a few decades away (Royo et al. 2017), but its birth is attributable to science-management cooperation.

By the mid-1990s, policymakers were eager to gather statewide data to assess whether the impacts reported from detailed research in the northwestern part of the state could be observed in forests statewide, and they turned to the SILVAH team to help them design a process to gather statewide data that could be analyzed using results from the deer enclosure study. The Pennsylvania DCNR BoF expanded its contract with the USDA Forest Service Forest Inventory and Analysis (FIA) unit to collect additional data on seedlings and interfering understory plants using methods that were similar to those taught in the SILVAH training sessions. FIA's Will McWilliams assembled a team of Forest Service and Penn State scientists to extend and fit the inventory practice into the FIA framework, and Harry Steele, from the SILVAH team, taught FIA crews how to conduct the new inventory. The results showed that 60 percent of plots taken across the state on sites where overstory shade was not limiting did not meet the standard for adequate advance regeneration (McWilliams et al. 1995), and that most of these plots were found in conditions identified as moderate to high deer impact levels.

These results increased the momentum for policy change. Public and private land managers and nongovernmental organizations were able to point to the studies to show that current deer management policy was having unsustainable ecological and economic impacts on Pennsylvania forests. Inside the Pennsylvania DCNR BoF state forester Jim Grace played a key role. In the Audubon Society, it was Executive Director Cindy Dunn. The Sierra Club's Don Gibbon led preparations for a Harrisburg, PA, workshop. Inside the Pennsylvania Game Commission the leadership of deer biologist Gary Alt was critical. Change was imminent, and interest in a landscape-scale demonstration of forest change in response to more sustainable management policies arose. The Sand County Foundation, a Wisconsin nongovernmental organization dedicated to the causes championed by Aldo Leopold, convened a breakfast meeting of public and private managers and scientists interested in deer forest interactions in Kane, PA. Could this group cooperatively manage deer, hunting, and habitat in a completely voluntary framework across ownership boundaries with some foundation support? The ease with which all participants said "yes" resulted in large part from the relationships—the community of practice—that were by then 30 years old.

The result was the Kinzua Quality Deer Cooperative (KQDC), founded in 2000. A 10-year grant from the Sand County Foundation funded the first decade of activities, which included collection of data concerning deer abundance, deer characteristics, habitat and vegetation variables, annual check stations to interact with hunters, and annual banquets to provide information about the response of the entire area to changing conditions as hunters reduced deer density (Stout et al. 2013). In 2010, Sand County Foundation sponsored an independent review of the KQDC by an international team of experts, and the results were very affirming. This affirmation and the value of the cooperative to participating managers led to a decision to continue funding KQDC with landowner contributions, and the cooperative remains active.

INTERFERING PLANTS AND THEIR TREATMENTS

Ristau (2019) and Horsley (2019) describe the important scientific advances and management guidelines that were developed through this line of research. Early research about regeneration challenges on the Allegheny Plateau highlighted the importance of abundant and well-distributed advance regeneration to stand-level regeneration success. Interfering plants that cast shade that was too dense to allow advance regeneration to establish, survive, or grow formed one important barrier. Horsley (2019) and Ristau (2019) led a series of studies to find effective treatments that would remove these barriers. Many of these studies were on land managed by partners. Hand-weeding, fire, and some herbicides were considered, and early small plot trials were undertaken. Herbicides proved most effective, and Horsley undertook detailed studies of various herbicides that examined doses and times of application. This work formed the basis for one of the herbicides becoming labeled for forestry use (Oust® herbicide with active ingredient sulfometuron-methyl).

Interactions with managers became extremely important as small-plot treatments shifted to operational tests and use. Because managers were already involved, they were poised to adopt the research results, and the management partners could focus on technology for applying herbicides at the operational scale. Ultimately, management organizations developed new equipment to improve application effectiveness. Horsley and Penn State Extension specialist Sandy Cochran hosted annual round-ups for those who were using the research results. At each round-up, Horsley updated the group on any new research, and representatives of each management organization (public and private) reported on what was and was not working and any new challenges they observed. With leadership from Ken Kane, a local forestry consultant, Dave Turner, a local heavy-equipment company owner, and the Pennsylvania DCNR BoF, most users across Pennsylvania's 4.2 million acres of public forests, nearly 1 million acres of forest land managed by the forest industry, and on some private land developed and adopted new equipment that used air-blast spray techniques. Scientists and managers discussed challenges of implementing research results at these annual meetings, which stimulated further research and improvements in the management guidelines for control of interfering vegetation (Horsley 1991).

Growing public concern about herbicide use stimulated further scientist-manager interactions. As managers began to adopt Oust® as part of their herbicide treatment toolkit, managers on the ANF undertook the environmental analyses required to use Oust® in the national forest. Some key stakeholders expressed concern about the impact of this herbicide on nontarget organisms. The forest silviculturist, Bob White, and ecologist, Brad Nelson, with Horsley and research wildlife biologist Dave deCalesta, met with these stakeholders in Pittsburgh and committed to a detailed study of nontarget impacts. Then Warren lab scientists hosted a special meeting at the Kane Experimental Forest (KEF). Scientists knew that the proposed study to determine the nontarget impacts of these operational herbicide treatments on nontarget organisms would occupy a great deal of research effort for at least a decade. Did managers support that level of investment by the local scientific staff? The answer was an overwhelming "yes" from managers working on public and private forests, and the ANF almost immediately engaged with the scientists to identify ten sites across the forest on which such research could be conducted. This research received consistent funding from the National Pesticide Impact Program and its successors, a great deal of in-kind support from the ANF, and led to landmark publications (Ristau et al. 2011, Stoleson et al. 2011, Trager et al. 2013).

SOIL NUTRIENTS AND FERTILIZATION

Long et al. (2019) describe the scientific advances associated with some of this research. Early tests of the role of site factors such as nutrition and moisture in the mid-20th century regeneration crisis did not show these as highly important causal factors. But black cherry (*Prunus serotina Ehrh.*) was known to be highly responsive to nitrogen fertilization, and managers were eager to use fertilization as a tool to hasten the height growth of seedlings out of the reach of deer. Auchmoody (1982) initiated studies of the effects of fertilization on black cherry. Among other things, this research showed that growth responses in height, diameter, and basal area of seedlings and saplings were greatest during the first 2 years after fertilization, with increases in height and diameter lasting for 4 to 5 years. A prescription of 200 pounds per acre of nitrogen and 44 pounds per acre of phosphorous sustained responses beyond the first year. Managers adopted these prescriptions operationally because they allowed regeneration to grow out of the reach of deer. The prescriptions were widely used on public and industrial forest lands through the early 1990s, when the Oklahoma City bombing resulted in dramatic restrictions on access to nitrogen fertilizers.

In the mid-1980s, managers approached Auchmoody with a new problem. Sugar maple (*Acer saccharum Marshall*), an important species in the region's forests, showed symptoms of decline. Crown health appeared weak on many trees. Sugar maple mortality, even in stands where the trees were in strong dominant and codominant positions, seemed to be increasing. Little or no sugar maple advance regeneration could be found. During the period when these observations were first brought to Auchmoody and others, society at large was engaged in vigorous debate about potential impacts of acid deposition (Likens and Bailey 2014), and some managers wondered if sugar maple decline could be associated with this problem. Auchmoody worked with managers from the Pennsylvania DCNR BoF to develop three hypotheses and design a test of three potential explanations for the dearth of sugar maple regeneration. On some plots, interfering plants were removed by herbicide treatment, on some, deer browsing was eliminated by fencing, and on some plots, soil chemistry, possibly changed by acid deposition, was changed by the additional of lime fertilizer. The Pennsylvania DCNR BoF provided four sites for this study and implemented the operational treatments. It contributed supplemental funding and contributions of in-kind labor for the 35 years that the study continued; this provided important information about sugar maple nutrient preferences (Long et al. 1997) and showed that lime fertilization improved sugar maple health and growth. The study became known as the lime study.

Auchmoody retired a few years after the study was launched. Managers were among those urging the scientific team to continue this research and link it to a better understanding of the relationships between landscape position, soil nutrients, and sugar maple health. In the context of the Allegheny Plateau community of practice, this interest in continuing research about soil nutrients and forest health, Steven Horsley agreed to continue the research, and he hosted a week-long field workshop for scientists and managers. Managers were invited to share their observations and contribute field sites to the tour, which ranged from the ANF to the sites of the lime study and included several sites owned by private forest industry organizations. Where were managers observing the most significant declines? Where, if anywhere, were they observing good sugar maple regeneration? Did the apparent link to soil nutrients confirm the hypothesis that soil chemistry in the region had changed in the recent past? In addition to local managers and scientists, Horsley invited USDA Forest Service colleagues from disciplines that were not represented on the local team.

Those who participated remember that week as highly stimulating intellectually and practically. Managers observed that differences in the health of sugar maple seemed to be associated with boundaries of historic glaciations and with landscape position; the worst declines were seen in plateau top positions on unglaciated sites, and the best regeneration was observed on glaciated sites. The field trip stimulated additional research linking sugar maple health to soil nutrients in landscapes across Pennsylvania, New York, and New England (Long et al. 2009). The quality of the early research also gave the research team access to archived soils collected by the then U.S. Department of Agriculture Soil Conservation Service for Pennsylvania soil mapping in 1967 and led to important ongoing work on long-term soil chemistry changes on the Allegheny Plateau (Bailey et al. 2005).

The study also showed that each of the two other major overstory species in the study areas—American beech (*Fagus grandifolia Ehrh.*) and black cherry—responded differently to the lime treatment. Through 35 years, there was no difference in beech growth or mortality between limed and unlimed plots. By year 10, however, it had become apparent that black cherry growth—and eventually survival—were lower on the limed than on the unlimed plots (Long et al. 2011). Continuity of the study through the full decade was key to learning this important result, underlining the importance of long-term research and ongoing relationships between managers and scientists to support such research.

The observations of negative impacts of lime fertilization on black cherry from the long-term liming study have been revisited in recent years as managers and scientists observe changes in black cherry. Current work, which involves managers and scientists working together, is again examining the effects of nitrogen/phosphorous fertilization on black cherry seedlings growing in the changed conditions created by the Clean Air Act Amendments of 1991 (Ristau and Long, unpublished).

OAK REGENERATION

Brose (2019) describes the science-management cooperation that occurred in the early 21st century to make the SILVAH system more appropriate and effective for mixed-oak forests of the mid-Atlantic region. The results were first documented in Brose et al. (2008), the textbook for the SILVAH-Oak training sessions. Brose (2019) also describes the critical roles that managers, and manager review of proposed inventory procedures and prescriptions, played in the development of SILVAH-Oak (Brose et al. 2008). He tells, for example, that it was manager feedback that led to consolidation of inventory for established and new oak seedlings for mixed-oak stands with site index below 65 feet at age 50.

The committee of managers and scientists that worked to develop SILVAH-Oak also identified research that was needed to confirm and refine management guidelines for sustaining mixed-oak forests. As with many other lines of science, the Pennsylvania DCNR BoF committed financial and in-kind resources to ensure that well-designed studies to address those research needs could be conducted, all on State Forest land. Other land management agencies, including the Pennsylvania Game Commission and the ANF, also provided land and in-kind services. One outcome of this large body of research was the award of a competitive grant from the National Joint Fire Science Program to Brose and colleagues from other parts of the mixed-oak forest range to synthesize knowledge of the role of prescribed fire in oak regeneration, resulting in both a landmark scientific paper (Brose et al. 2013) and a manager's guide to using what this synthesis showed (Brose et al. 2014). Research concerning the use of prescribed fire as a tool in the oak regeneration process had been ongoing for decades; however, this synthesis represented a genuine breakthrough. By placing each study that provided enough information to do so into a matrix that included the stages of seedling development and the season of the fire, Brose and his colleagues were able, for the first time, to provide generalized guidelines for when and how to use prescribed fire to regenerate oak.

Prescribed fire is a frequently recommended silvicultural tool in SILVAH-Oak. As SILVAH-Oak prescriptions became more widely used in Pennsylvania, the positive outcomes of appropriate use of prescribed fire became apparent, yet Pennsylvania laws regarding the use of prescribed fire did not protect even the best-trained and best-prepared practitioners from liability. Managers and users of SILVAH-Oak prescriptions worked together to pass a new public law in Pennsylvania, the Prescribed Burning Practices Act (P.L. 76, No. 17) in July 2009. This law charged the DCNR to develop standards for prescribed burn plans, prescribed burn manager training, and a process for approving prescribed burns. The law also ensured immunity from civil and criminal prosecution for landowners and practitioners who allowed and conducted prescribed burns according to the standards and training requirements.

Northern Research Station (NRS) scientists Kurt Gottschalk and Gary Miller from West Virginia were key members of the SILVAH-Oak development team. As they became increasingly familiar with the role the training sessions could play in fostering science-management cooperation and sustainable forestry, they suggested bringing the training sessions to West Virginia. Similarly, organizers of the early training sessions invited Joanne Rebbeck, a plant physiologist and collaborator from the NRS in Ohio, to become part of the SILVAH team. Under her leadership, training sessions began in Ohio in 2005. The timing was propitious, because efforts were already underway to increase cooperation among public agencies in Ohio to sustain oak forests there. SILVAH-Oak became a foundation for a community of practice in Ohio that is now supported by a consortium that includes the Wayne National Forest, the Ohio Division of Forestry, and the USDA Natural Resources Conservation Service. It will soon include the Ohio Division of Wildlife and others. Some of the efforts of this community of practice are described in Peters and Rebbeck (2019).

WILDLIFE HABITAT AND SILVICULTURE

As various organizations began using the SILVAH-Oak prescriptions to ensure continued oak abundance in mixed-oak forests, wildlife managers began to attend the SILVAH-Oak training sessions in greater numbers. Oak forests provide essential benefits for many wildlife species, and public agencies and nongovernmental organizations with a mandate to sustain wildlife habitat found SILVAH-Oak to be a valuable tool.

At the same time, scientist Scott Stoleson was completing research that showed the importance of early successional habitat to many migratory songbirds in the post-fledging period (Stoleson 2013). Other research was showing the benefits of the conditions created by shelterwood seed cuts, especially in white oak stands, to cerulean warblers (*Dendroica cerulea*) and other bird species of conservation concern (Stoleson 2004). An allied community of practice began to form to increase, update, and publicize the wildlife habitat information available from SILVAH and the associated NED software. Stoleson, SILVAH programmer Scott Thomasma, and Helene Cleveland, who had developed a matrix of Pennsylvania wildlife species habitat requirements for NED (Cleveland and Finley 1998), co-led this effort. They formed a working group with several wildlife managers that accomplished these improvements, which are now incorporated in SILVAH and NED (Thomasma and Cleveland 2019). Stoleson (2019) provides a synthesis of what is known about the interaction of silviculture and wildlife habitat that builds on the products from the working group and informs the SILVAH system for mixed-oak, Allegheny, and northern hardwood forests. This results of this work form a regular part of all SILVAH training sessions.

BLACK CHERRY DECLINE

Beginning early in the 2000s, managers and scientists began noticing changes in the ecology of black cherry in the Allegheny High Plateau ecoregion. Early discussions focused on decreased frequency of abundant black cherry seed crops and expanded to observations of reduced growth and competitiveness of black cherry seedlings, while those of black birch (*Betula lenta* L.) became more competitive. Eventually, these discussions included observations of crown dieback and of increased frequency and apparent virulence of cherry leaf spot (*Blumeriella jaapii*) attacks on seedlings. By the time of the recession in the late 2000s, as cherry timber prices declined substantially, purchasers of black cherry timber were complaining of a defect that became known as dark rings. Dave Trimpey, a manager with Collins-Kane Hardwood, approached Bob Long about this specific defect. Trimpey and other managers helped Long identify sites on which trees with dark rings had been found. Long associated these with previous defoliations and found important patterns. Long brought in experts from the Forest Products Laboratory and together they published results showing the relationship with defolation and the wood properties associated with the dark rings (Long et al. 2012).

In 2014, Long and ANF Silviculturist Andrea Hille received a grant to remeasure all the forest health plots across the ANF that included black cherry. By 2015, because black cherry vigor and survival had changed, the SILVAH research team decided they could no longer teach the current research guidelines for regenerating Allegheny hardwood stands. They began to assemble data from long-term and recent studies to better understand emerging patterns. On September 23, 2015, the SILVAH team assembled representatives of all key management partner organizations at the KEF to spend a day pooling observations and forming hypotheses. Lab teams assembled data from two stem-reconstruction studies, which suggested that before 1995 black cherry seedlings and saplings had consistently outcompeted black birch; after 1995 the opposite appeared to be true. They assessed linkages between climate data and these changes and found little. They brought in data about the scale and severity of defoliations of black cherry. Long's data concerning seed production confirmed that seed crops were less frequent and production was lower. They also showed that age of stand was not correlated with seed production. Emerging data from the revisited health plots confirmed an increase in black cherry mortality compared to earlier measurement periods, and when the Pennsylvania DCNR BoF was asked to query its permanent inventory plots for the High Allegheny Plateau ecoregion, researchers found the same trend. Data from the National Acid Deposition Program weather station on the KEF showed that nitrogen inputs from acid deposition had decreased to levels not reported since the 1960s, so old data about cherry responsiveness to nitrogen fertilization were also brought to the meeting.

Each manager present was asked to report observations, and new insights emerged from the conversation. Many foresters present were observing better cherry seedling health, survival, and growth in stands with low proportions of cherry in the overstory, and everyone was seeing cohorts of black cherry seedlings eliminated, sometimes in more than one successive year, by black cherry leaf spot. Some participants remembered that sulfur has fungicidal properties and wondered if the reduction in sulfate deposition might be playing a role in the changed ecology of cherry seedlings.

The research responding to these observations is at an early stage, and some studies are awaiting funding. But the collaboration between managers and scientists regarding this this emerging issue reaffirms the patterns that have been successful in the past.

LESSONS LEARNED

Together, scientists and managers in the High Allegheny Plateau ecoregion have learned several key lessons about sustaining the benefits of science-management collaboration. Our summary for this chapter has two parts. Table 1 highlights some specific outcomes from the half-century of collaborative work that the SILVAH community of practice has completed. We also show specific instances from the examples above that illustrate the general principles of science-management collaboration.

1) Collaboration between scientists and managers sharpens hypothesis formation by increasing the number of observations and perspectives on which hypotheses are based.

The best examples of this occurred in the silviculture, soil nutrient and fertilization, and oak regeneration lines of research. The Stand Culture and Stand Regeneration scientist-manager tour in the early 1990s led to the development of allied decision support software, NED. The 1995 sugar maple decline tour to look at research and manager-selected sites demonstrating good and bad sugar maple health and regeneration focused the attention of the entire team on the landscape distribution of key nutrients. This led to more studies, including a landscape study and a study to test soil nutrient changes over time. For oak regeneration, the team of managers and scientists convened by the Pennsylvania DCNR BoF explicitly identified and prioritized research needs and developed a new SILVAH framework into which the results of those studies could be incorporated as they became available.

2) Collaboration accelerates, diversifies, and focuses site selection for designed experiments and can support more complex designs by providing in-kind services for study and treatment installation.

At least four lines of science provide excellent examples of this principle. The original deer enclosure study involved four landowners and in-kind support for fence construction. The current study of the interaction of landscape food production and deer impact at specific sites involves seven landowners, all of whom implemented the key central shelterwood harvest as an in-kind service. Most of the oak regeneration work and the original soil nutrient study of sugar maple decline involved Pennsylvania DCNR BoF personnel identifying potential sites and collaborating with scientists to implement treatments. The study of nontarget impacts of operational herbicide treatments depended on close collaboration with ANF managers to identify sites and implement treatments.

3) Managers help scientists conduct better research by influencing the direction of a research program and by supporting (for example, through pilot studies) excellent work that attracts competitive funding.

The KQDC and the original deer enclosure study both pointed to the interaction of landscape forage production with actual deer impact on regeneration in managed stands. Those studies provided the preliminary results that enhanced the competitive success of the application to the USDA Applied Forestry Research Initiative grant program that provided 5 years of support to the resulting landscape-scale study at 25 locations across the region. Early research on interfering plants and their management formed the essential underpinning for the competitive grants awarded to the herbicide-diversity study. Preliminary research associated with oak regeneration was instrumental when Brose and his colleagues succeeded in the Joint Fire Science Competitive Grant program to synthesize the literature concerning the relationship of oak regeneration and prescribed fire.

4) Scientists can expand the net of expertise available by bringing in colleagues from other regions with relevant specialties.

As the initial sugar maple decline research began to yield results, scientists at the Irvine Lab recruited other Forest Service researchers with relevant expertise, including Robert Long, a research forest pathologist, Scott Bailey, a research ecogeologist, and Richard Hallett, a research forest ecologist with experience in nutrient-forest health interactions. Managers from the Pennsylvania DCNR BoF brought experts from their Forest Health division, including Barry Towers and Tom Hall, and managers to assist in data collection, especially Paul Lilja.

5) Regular interactions through which a common vocabulary and framework are developed increase the efficiency of describing emerging problems and promotes shared ownership of the work.

The SILVAH training sessions and frequent problem-focused interactions form one core of the community of practice. New foresters participate soon after beginning work in the ecoregion, where they are exposed to the SILVAH framework and the vocabulary that has developed to describe inventory results and stand and landscape attributes that influence management outcomes. Managers at every level participate in the training sessions, research updates, professional meetings, and working groups that rely on the vocabulary and framework. The best examples from this chapter that highlight the benefits of the shared framework are the early work on oak regeneration that became SILVAH-Oak, including beta-testing of new inventory and prescription processes by managers and the recent work on black cherry decline.

6) As managers participate in problem selection and in the design of experiments that are directly relevant to management practice, they gain confidence in research results and become more willing to adopt new practices and support policy changes based on the research.

The silvicultural practices embodied in the SILVAH training sessions and decision support software are standard operating procedure in many public agencies in Pennsylvania, Ohio, New York, and Maryland, and they inform silvicultural practice in many private management agencies. When the initial SILVAH inventory process was first announced, there might have been great resistance, because regeneration plots that were essential to the inventory could be conducted only during the growing season. This was an expensive change to implement, but because managers had been involved from the inception of the studies that led to these changes and could see the benefits in the research areas, adoption was quick and widespread. Penn State extension foresters worked with managers and scientists at the Irvine Lab to develop an application of SILVAH processes and practices for private landowners (Finley et al. 2007).

At least two major forest policy changes in Pennsylvania during the 50 years of science-manager collaboration are strongly associated with the SILVAH community of practice. As results from the deer enclosure study began to accumulate, land managers were able to show policymakers these results on the ground and tell policymakers about the impact to their bottom line. These actions, combined with productive use of the research results by leaders in the Pennsylvania DCNR BoF and the Pennsylvania Game Commission, contributed substantially to the late 20^{th} century and early 21^{st} century changes in deer management policy in Pennsylvania. These changes have increased the sustainability of Pennsylvania's forests.

The other important example of policy change regards prescribed fire. Pennsylvania land trusts and others used results from SILVAH-Oak research, including the meta-analysis of prescribed fire-oak regeneration interactions and the availability of study and demonstration sites, to change Pennsylvania's liability laws regarding prescribed fire. This resulted in a well-defined process that, if followed and documented, protects those who used prescribed fire from personal liability. This change in policy has increased the appropriate use of prescribed fire for oak regeneration benefits.

7) Over time, a community founded on mutual respect emerges, and scientists and managers coproduce knowledge and improved practices.

The current work to develop interim strategies for stands that are affected by black cherry decline and other forest health challenges through a working group emerging from the Allegheny High Plateau Forest Health Collaborative is the best example of the community of mutual respect and the coproduction of knowledge. As research to document the causes of the problem and develop new management practices to sustain forest benefits continues, managers and scientists together are using the SILVAH vocabulary and framework to develop a prioritization or triage scheme for which stands most urgently require silvicultural intervention (as seed source is threatened by imminent mortality, for example) and to develop silvicultural guidelines for such stands.

Equally important is the benefit to individual foresters and scientists that participate in such a community. It is rewarding in the deepest professional sense to always feel that one's work is part of a larger whole and contributes to the good of the forest in which one works. And, over time, warm personal relationships enhance these professional rewards.

Table 1.—Selected outcomes of the SILVAH community of practice for each illustrated line of science.

Line of Science				
Silviculture	**Adoption:** The SILVAH decision support system and training session textbooks are standard operating procedure on more than 4 million acres of public land and many more on private land	**Science leadership:** The SILVAH relative density measure was the model for the measure of relative density now used by FIA across the eastern United States	**Science leadership:** The SILVAH understory inventory procedure was the model for the understory inventory procedure used by FIA across the northern region	
Deer and forest management	**Policy:** Changes in deer management in Pennsylvania were influenced by results from this research, especially by the 1980s deer exclusion study	**Policy:** The Pennsylvania Game Commission uses the FIA understory measure (based on SILVAH) to assess forest health in each of Pennsylvania's deer management units	**Science leadership:** Top 3 articles from this research have been cited by other scientists around the world more than 1500 times	**Adoption:** Land managers fence regeneration harvests to exclude deer where SILVAH inventory indicates overabundance; are now looking at landscape-scale patterns that influence land management
Interfering plants and their treatment	**Adoption:** Silvicultural prescriptions based on this research are used by managers of more than 4 million acres in Pennsylvania alone	**Policy:** The registration of OUST® for forestry use was conferred based on this research	**Science leadership:** The decade-long study of nontarget impacts of operational herbicide use informs future research and management	**Technology development:** Science-manager collaboration led to development of new application equipment by users of these research results
Soil nutrients and fertilization	**Adoption:** Early results of this research led to routine operational fertilization treatments on public and private land throughout the Allegheny Plateau ecoregion to help regeneration gain height quickly	**Science leadership:** As the high-quality research on sugar maple decline accumulated, managers of soils collected in the 1960s gave SILVAH researchers access to those soils and sites, creating the basis for what is now a 50-year record of changes in soil chemistry	**Adoption and adaptive management:** Managers on the ANF are collaborating with SILVAH scientists to test fertilization in stands where black cherry seedlings are slow to establish and gain height	
Oak regeneration	**Adoption:** The SILVAH computer program and training session textbook form the basis for interagency collaboration to sustain oak in Ohio	**Adoption:** The SILVAH system is standard operating procedure on more than 4 million acres in Pennsylvania alone. Also used in OH, WV, MD, NY, and beyond	**Policy:** As research results and results from adoption showed the importance of prescribed fire in oak regeneration, Pennsylvania adopted P.L. 76, No. 17 to limit liability for well-trained users of this technique	**Science leadership:** The meta-analysis of the fire-oak hypothesis conducted by Brose et al. (2012) synthesized results of more than 30 studies brought order to this important body of work
Wildlife habitat and silviculture	**Science leadership:** Research conducted by the SILVAH team was the first to show that birds using early successional habitat were in better premigration condition than those that used closed forest habitats	**Technology development:** NED was among the first tools to help forest managers link in-stand condition, collected using SILVAH inventory techniques, to habitat needs of individual species		
Black cherry decline	**Hypothesis development:** The SILVAH community of practice has pooled observations about black cherry decline with long term data from the SILVAH science team to form key hypotheses in this emerging research field	**Science leadership:** Collaboration between land managers and SILVAH scientists enabled analysis of site-specific factors such as defoliation history to be analyzed as explanatory factors in the development of dark rings	**Adaptive management:** While scientists seek funding for detailed studies of causes and management responses to black cherry decline, multiple land management agencies are conducting pilot studies of potential treatments	

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RECOGNITION, RESPONSE, AND RECOVERY: DEER IMPACT RESEARCH IN ALLEGHENY HARDWOOD FORESTS

Alejandro A. Royo and Susan L. Stout[1]

Insights for Managers

- **Scientists and land managers from this region were among the very first in North America to document deer overbrowsing impacts in forests and to propose the interdependence between forest and game management.**
- **Deer-forest research in the region helped transform forest regeneration inventories into a flexible and biologically realistic stocked plot approach that considers species' growth, survival, and sensitivity to browsing as well as deer browse pressure.**
- **During the 1980s, a groundbreaking controlled browsing experiment was the first to examine how variation in deer browsing and forest overstory conditions could drastically alter and impoverish vegetation, causing long-lasting impacts that permeated throughout insect and animal communities.**
- **Moreover, it was the first experiment to demonstrate how moderate deer densities (i.e., 10 to 20 deer per square mile) are compatible with plant and avian diversity in these forests.**
- **More recently, research suggests that coordinated and adaptive management that engages policymakers, land managers, and hunters can maintain deer herds at healthy densities (~13 deer per square mile) and benefit plant species populations and plant community richness; however, these results occur on decadal timescales.**
- **Our latest findings provide strong evidence of the linkage between forest management activities and deer browse impact. Specifically, these results suggest that when ~20 percent of the landscape within the typical home range of deer contains forage-rich, early-successional habitat, the negative impacts of browsing on vegetation at local (i.e., stand) scales lessen and ultimately disappear.**
- **Taken together, this research provides compelling evidence of the critical role humans play in sustaining diverse forests and healthy herds through management, policy, and recreation decisions. Sustaining and improving the ecosystem services provided by our forests will require continued relevant science and cooperation among policymakers, land managers, and hunters.**

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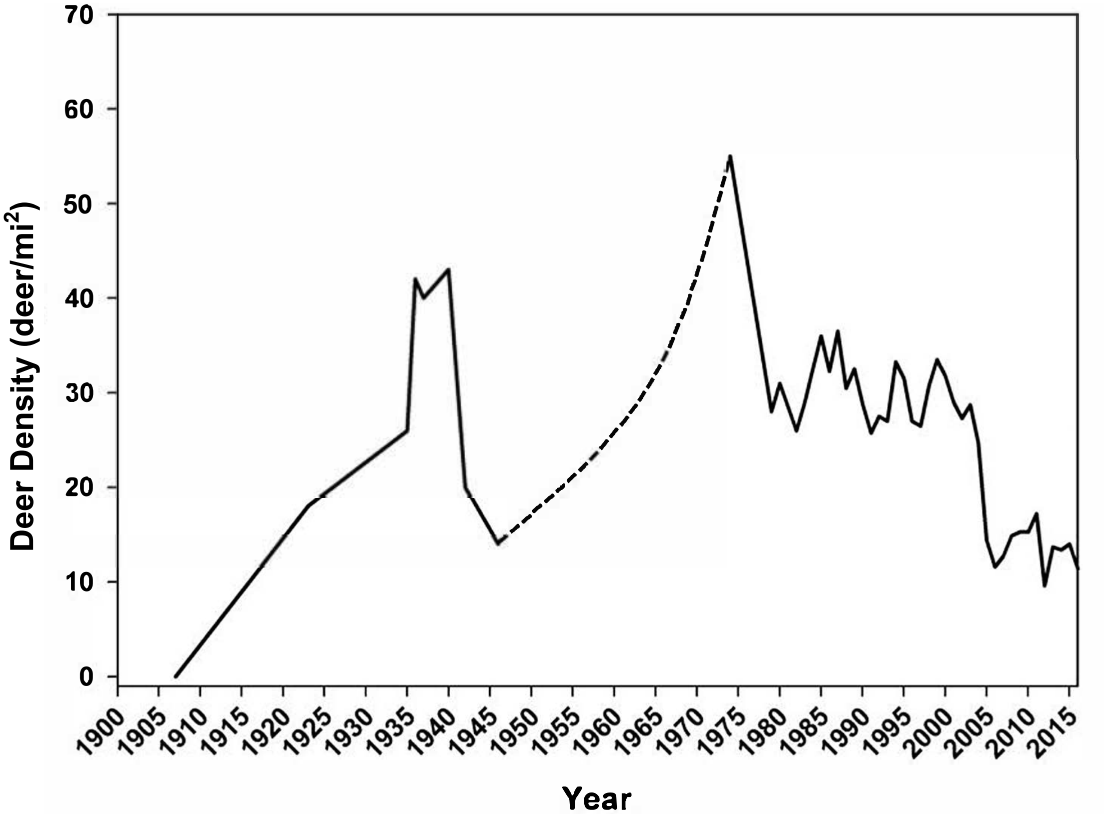

Figure 1.—White-tailed deer population trends in northwestern Pennsylvania, 1907-2017. Dashed curve represents a time period (1947-73) for which no quantitative data are available, but for which we assume an exponential increase in populations as timber harvesting increased in the late 1950s and 1960s. The sharp decline observed beginning in 2003 is a direct result of the targeted deer harvests within the KQDC project area.

INTRODUCTION

During the early decades of the 20th century the confluence of two major alterations to forest and wildlife population dynamics occurred in the northern tier of Pennsylvania; namely, the near-complete harvesting and resultant regrowth of all forests in the region coupled with the extirpation and subsequent reintroduction of white-tailed deer (*Odocoileus virginianus*) (Redding 1995). In the ensuing years, abundant early-successional habitat, the absence of apex predators such as wolves and mountain lions, and lax game management policies resulted in a population explosion of deer to levels that far exceeded precolonial estimates (<11 deer per square mile) (McCabe and McCabe 1997) and that were generally above levels compatible with healthy forest regeneration (≤20 deer per square mile) (Horsley et al. 2003; Fig. 1).

By the early 1930s deer populations exceeded carrying capacity throughout the forests of northern Pennsylvania and were causing damage to tree regeneration and understory plant communities. This was documented in some of the earliest papers about deer browsing impacts in the scientific literature (Ehrhart 1936, Frontz 1930, Ostrom 1937). For example, Ashbel Hough, an early USDA Forest Service Northeastern Research Station scientist working in the Allegheny National Forest, declared it was evident that deer overbrowsing had nearly eradicated understory hemlock (*Tsuga canadensis* L.) and witch hobble (*Viburnum lantanoides* Michx.) throughout the Tionesta Old Growth forest during the 1930s (Hough 1965). Several other researchers and managers sounded similar alarms (Gerstell 1938, Leopold et al. 1947, McCain 1941). This initial period of deer overabundance, however, lasted only a couple decades. Toward the end of the 1930s, deer herds faced an ever-diminishing carrying capacity as forests grew into forage-poor stem-exclusion (sapling) conditions which, coupled with successive severe winters beginning in 1938-39, caused deer populations to collapse to approximately 14 per square mile by 1946 (Hough 1949). Given the collapses in deer numbers and reductions in the local timber industry with the onset of World War II and because of the widespread stocking of nonmerchantable sizes classes, deer population data were not gathered between 1947 and 1973. However, as the maturing second-growth forests began to yield sawlog-size timber and forest industry returned, deer populations climbed. By 1960, even-aged silvicultural systems were once again utilized by a burgeoning forest industry and, with the concomitant creation of forage-rich, early-successional habitat, deer populations rebounded and remained excessively high throughout much of latter half of the 20th century (Jordan 1967, Redding 1995).

By the late 1960s regeneration failures following even-aged harvests were commonplace. The USDA Forest Service Research branch responded to the requests of local land managers for help in solving these issues and initiated a coordinated research agenda to assess the causes of these failures and to provide guidelines for managers to sustainably regenerate forests. From very early on, researchers strongly suspected deer contributed to the regeneration failures (Grisez 1959, Jordan 1967, Shafer et al. 1961). Over the following five decades the Northeastern Forest Experiment Station, now known as the Northern Research Station (NRS), conducted a series of related experiments to elucidate the role white-tailed deer played in shaping forest dynamics and biodiversity. Over time this research program evolved. After seminal exclosure studies documented browse impacts on regeneration, complex manipulative studies assessed browse legacies on biodiversity across a range of deer densities and forest conditions. These were followed by long-term monitoring of vegetation changes across landscapes after deer herds were reduced. The current, culminating experiment is testing how variation in habitat composition at large spatial scales affects browse impact at local scales. Collectively, this body of work is internationally recognized as very important, provides solutions to important management problems, and informs policy.

THE GROWTH AND DEVELOPMENT OF A RESEARCH PROGRAM

Recognition of Deer Impact on Regeneration

In 1967 researchers in the Northeastern Forest Experiment Station initiated a study to ascertain how frequently and under which conditions regeneration failures occurred. Although the research did not explicitly consider deer, researchers knew that browsing reduced advance regeneration abundance and, therefore, could be directly responsible for the regeneration failures. Using preharvest and postharvest regeneration tallies in 65 operational even-aged regeneration harvests on the Allegheny National Forest, researchers revealed that 46 percent of the harvests failed to successfully regenerate forests following clearcuts (Grisez and Peace 1973). Moreover, researchers found that the single best predictor of which areas would regenerate successfully was whether stands contained abundant and well-distributed advance regeneration. These and other results (e.g., Leak 1969) on the importance of both abundance and spatial distribution of regeneration in predicting regeneration success led to a shift in inventory methods. Many foresters did not conduct understory inventories before harvests, and when this was done, decisions were based on the number of advance seedlings per acre. The NRS developed a “stocked plot” concept wherein decisions were made based on the proportion of plots that met acceptable stocking criteria (Grisez and Peace 1973, Marquis et al. 1975).

In tandem with the regeneration outcomes study, scientists capitalized on a set of deer-excluding fences and paired areas subject to ambient browsing in 13 clearcuts throughout the Allegheny National Forest. These clearcuts were established in the 1950s and 1960s to determine the degree to which white-tailed deer were responsible for regeneration failures. Marquis (1974) and colleagues found that of the 13 stands, 12 (92 percent) successfully regenerated within the fence, whereas only 5 (38 percent) regenerated under ambient browsing. Moreover, when analyses were restricted to the 8 stands that failed to regenerate under ambient browsing, in 7 of the 8 cases exclosures resulted in successful regeneration. Hence, Marquis (1981) concluded deer were directly responsible for 87 percent of the regeneration failures in clearcuts in the Allegheny Plateau region. Researchers also noted that the conditions required for regeneration success differed between treatment areas. Within fences regeneration success was achieved with far fewer seedlings. This recognition established the foundations for more flexible and biologically realistic stocking criteria that varied in response to deer browse pressure. Early guidelines focused on black cherry (*Prunus serotina* Ehrh.), the most abundant species at the time, whereas, over time, guidelines were developed to include other species with different growth and survival rates as well as variation in sensitivity to deer browsing (Brose et al. 2008, Marquis and Bjorkbom 1982, Marquis et al. 1992).

Forest Diversity Responses to Variable Deer Densities

Following the experimental confirmation that overbrowsing was largely responsible for regeneration failures and the associated work on developing silvicultural guidelines given deer browsing, (e.g., fencing, fertilizer) (Marquis and Brenneman 1981), the question then became understanding how different deer densities would affect forest diversity. To address this, the Northeastern Forest Experiment Station initiated a groundbreaking controlled browsing experiment. In this study, vegetation responses in uncut, thinned, and clearcut areas were monitored for 10 years under 4 different deer densities: 10, 20, 38, and 64 deer per square mile (Horsley et al. 2003, Tilghman 1989). This seminal work conclusively demonstrated that the rate and trajectory of regenerating forest communities are strongly mediated by deer browsing and vary with the sensitivity of species to deer browsing.
Specifically:

- More palatable or browse-intolerant species such as brambles (*Rubus* L. spp.), red maple (*Acer rubrum* L.), and birch (*Betula* L. spp.) decreased in abundance and were limited in height.
- Increasing deer densities favored species such as black cherry and hay-scented fern (*Dennstaedtia punctilobula* Michx. Moore) that are tolerant to browsing or are avoided by deer (Horsley et al. 2003, Nuttle et al. 2014, Tilghman 1989).
- Selective browsing impacts to species were so pronounced that species composition and diversity changed depending on the level of browse pressure. At higher deer densities, regenerating forest stands became depauperate and strongly dominated by browse-tolerant species; at the lowest deer densities the fast-growing and highly palatable pin cherry (*Prunus pensylvanica* L.f.) flourished and suppressed regeneration of other hardwood species (Ristau and Horsley 1999, 2006).

These findings suggest that the relationship between deer browsing and forest regeneration may be unimodal: high deer herbivory pressure facilitates dominance by browse-tolerant species, and light herbivory pressure promotes dominance by fast-growing pioneer species. Thus, forest productivity and diversity may be highest under moderate browse pressure (see also Royo et al. 2010a). Indeed, the authors suggested that densities of 20 deer per square mile would be compatible with hardwood regeneration, although somewhat lower densities (~10 deer per square mile) may be necessary to restore diversity to the overall plant community.

This landmark study also revealed that by altering the patterns of vegetation development and composition, deer browsing can alter the diversity and dynamics across trophic levels. For example, deCalesta (1994) found that the suppression of tree regeneration into the midstory by deer browsing reduced intermediate canopy nesting bird richness and abundance by 30 percent and 37 percent, respectively (see also McGuinness and deCalesta 1996). As these stands matured, these direct and indirect deer-induced changes to forest vegetation composition and structure "ricocheted" throughout the trophic chain (deer → tree → insect → bird communities) causing declines in insect and bird densities 30 years after stand establishment (Nuttle et al. 2011). Deer-induced changes to vegetation dynamics and composition altered other interspecific interactions. For example, the dense and persistent hay-scented fern layer promoted by excessive browsing (Nuttle et al. 2014) exerts a strong competitive effect on tree seedlings and secondarily enhances seed and seedling predation rates by small mammals, thus further suppressing tree establishment (Horsley 1993, Royo and Carson 2008).

Monitoring Recovery and Impact across Landscapes

By the beginning of the 21st century, browsing-induced changes to forests were so extensive that the very baseline of what constitutes a normal forest had shifted (Stout and Horsley 2004). Forest managers often had to employ extraordinary measures including herbicide applications to control interfering vegetation, fencing to mitigate deer browsing, or both, to sustain diverse and abundant seedling recruitment on a stand-by-stand basis (Marquis et al. 1992). Moreover, researchers acknowledged that the degraded habitat conditions throughout the landscape would continue to complicate management and be unfavorable to the deer herd and, by extension, to the hunting experience. Thus, beginning in 2000, a group of private and public land managers, scientists, hunters, and others began working across a 74,350-acre landscape on an adaptively managed and cooperative project whose joint goal was to improve forest habitat, deer herd health, and the hunting experience. The group used newly available deer management programs offered by the Pennsylvania Game Commission, most importantly the allocation of additional and targeted antlerless hunting permits, to begin the ambitious Kinzua Quality Deer Cooperative (KQDC) management and monitoring project (Reitz et al. 2004, Stout et al. 2013).

Within the KQDC, aggressive deer harvests coupled with strong hunter engagement resulted in a rapid and sustained reduction in deer densities of approximately 50 percent (Figure 1). Vegetation monitoring results demonstrated that browsing on hardwood species inversely tracked deer densities: as deer densities decreased, browsing also decreased. By 2007, 3 years after deer herd reductions, populations of known browse-sensitive phytoindicators including *Trillium* L. spp., *Maianthemum canadense* (Desf.) and *Medeola virginiana* (L.) experienced substantial (32 percent to more than 100 percent) increases in abundance, size, and reproductive success (Royo et al. 2010b). Similarly, regeneration of browse-sensitive tree species including red maple (316 percent increase), sugar maple (*A. saccharum*; 382 percent increase), birch (438 percent increase), white ash (*Fraxinus americana* L.; 466 percent increase) improved in the 12 years following herd reductions. Additionally, cucumber magnolia (*Magnolia acuminata* L.), a browse-sensitive species virtually absent at the start of the monitoring, became the 5th most common species in the regeneration layer by 2016. As tree recruitment improved across the landscape, fencing of regeneration harvests, a management recommendation triggered when desirable regeneration is scant or at risk

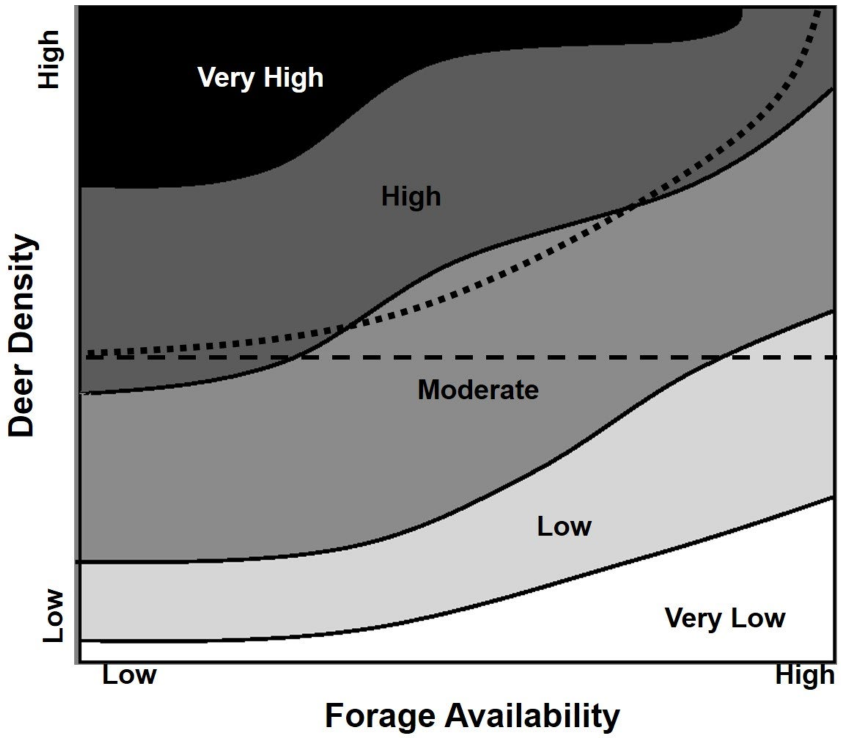

Figure 2.—Conceptual model illustrating local browse impact (shaded isoclines) as a function of deer density and forage availability. Dashed line illustrates a constant ungulate density exerting high to low impact depending on forage availability. Dotted line represents an ungulate population that increases over time as forage increases, thus nullifying any forage-mediated reductions in browse impact.

of herbivory, plummeted. Indeed, Collins-Kane Hardwood, one of the participating land managers of the KQDC, experienced a decline in fenced acreage from an average 129 acres/year to zero (with associated savings that averaged of $22,712/year) while other landowners like the Allegheny National Forest stopped erecting fences within the KQDC entirely (Stout et al. 2013). Lastly, after more than a decade of sustained deer herd reductions, the baseline itself shows signs of shifting again to conditions representative of what our forests might look like without too many deer. In addition to the responses detailed above, vascular plant species richness within the KQDC increased by 12.6 percent at the small plot level (number of species/m^2) and by 16.2 percent whole plot (0.3 acre) scale by 2016, 14 growing seasons after lowering the deer herds (Royo, unpubl. data[2]). Continued monitoring will ascertain whether these increases in species richness persist. But what is clear is that recovery of the plant community requires a sustained commitment to maintaining deer herds at a level compatible with their habitat on decadal timescales.

In the first decade of the KQDC project, private land partners created about 11,000 acres of early successional habitat through timber harvests (~15 percent of the land area enrolled in the KQDC) as the Allegheny National Forest conducted the environmental analyses necessary to concentrate harvesting throughout its landholdings enrolled in the KQDC during the second decade. Interestingly, private land managers achieved diverse regeneration of their harvests without fencing, even though their properties often had higher deer densities than the National Forest lands. These observations bolstered a hypothesis that was formulated based on evidence from the controlled browsing experiment that deer impact on forest vegetation is a joint function of deer density and the amount of forage available to deer within their home range (Fig. 2) (Marquis et al. 1992). This hypothesis extends the concept of the ecological carrying capacity by considering the habitat's influence on the deer herd and the reciprocal impact of the deer herd on the habitat (deCalesta and Stout 1997).

[2] Royo, A.A. 2016. Kinzua Quality Deer Cooperative summer 2016 data. On file at USDA Forest Service, NRS-02, Irvine, PA 16365.

From a forest management perspective, the concept that variability in habitats at large scales could modulate browse impacts locally was attractive because it suggested a solution whereby land managers could proactively counter overbrowsing by creating forage-rich, early-successional habitat at the appropriate spatial and temporal scales (deCalesta and Stout 1997, Miller et al. 2009). Despite the appeal, empirical support of this concept remained generally anecdotal. For example, during the 1980s, high browse impact and regeneration failures were prevalent throughout the Allegheny National Forest, where harvest rates at the time created relatively low proportions of forage-producing habitat (4 percent clearcut + 13 percent thinned). In contrast, even under high deer densities, regeneration failures did not occur where forage-producing habitat was abundant either in the controlled browsing study (10 percent clearcut + 60 percent thinned) (Horsley et al. 2003) or in a nearby 1100-acre demonstration area (13 percent clearcut + 33 percent thinned) (Stout et al. 1995).

To rigorously test the hypothesis that deer impact on vegetation was a function of both deer density and forage availability, the NRS initiated a deer impact study in 2012: a large-scale hybrid experimental approach that incorporates a manipulative (fence/control) treatment to test how localized (stand-level) browse impact by white-tailed deer varies among 23 broadly distributed sites that vary in deer densities and relative abundance of various habitat types at larger (640-acre) scales. The area characterized was specifically chosen to encompass the typical home-range size of deer within northern hardwood forests (Tierson et al. 1985). This study emphasized the proportion of forage-rich habitats created by management (recent [≤5 years] timber harvests + herbaceous openings [including oil and gas openings and pipelines] + agricultural areas) versus forage-poor habitats (stem-exclusion stands; clearcut areas >5 years, but ≤17 years). Initial results from this study suggest that while deer browsing reduced plant community richness and cover by as much as 53 and 70 percent, respectively, browse impact varied in response to the relative abundance of forage containing habitats. Specifically, relative to fenced areas, browse impact weakened and ultimately disappeared as the proportion of forage-rich habitats created by management increased to ≥20 percent. Conversely, vegetation grew increasingly depauperate as landscapes contained greater proportions of forage-poor habitats, particularly when browsed (Royo et al. 2017).

These preliminary results demonstrate that even-aged forest management, when practiced at the appropriate scales, can alleviate browse pressure in the near term. The results also strongly suggest that the effect is temporally dynamic, because changes to vegetation structure, composition, and abundance that occur during succession eventually reverse and intensify browse impact. Stated plainly, harvest operations create forage-rich habitats that initially mitigate browsing; however, as these areas mature into forage-poor, stem-exclusion habitat, deer browsing intensifies on any remaining areas that still provide forage. As this experiment matures and yields further data, we hope to refine our guidelines on the spatial and temporal scales of forest management operations that simultaneously provide complementary benefits to wildlife, biodiversity, and sustainable management. Moreover, these data will allow us to refine recently developed forest dynamics models that explicitly consider how forage quantity and quality at various scales can modulate browse pressure on regenerating forest stands (LANDIS-II) (De Jager et al. 2017).

SUMMARY

Since the early 1900s, forest and game management practices across the northern tier of Pennsylvania have created an exceptional model system in which to study deer-forest interactions. Fortuitously, Forest Service researchers and a cadre of engaged public and private land managers have unswervingly studied these dynamics for nearly a century. The international scientific community recognizes this body of work, which provide guidelines for key management issues regionally. This long-term research program is a model of the steady and accumulative progress that is fundamental to discovery. Early ideas or hypotheses were tested by experimentation and the results, over time, were distilled into a more accurate understanding of the system. For example, as early as 1936, Ira Gabrielson commented on the interdependence of forest habitat and deer and reasoned that concentrating harvests within a landscape up to a threshold amount of 25 percent may benefit plants and wildlife (Gabrielson 1936). Nearly 85 years later, landscape-level studies such as the KQDC and deer impact studies are finally providing empirical evidence to refine these ideas and provide meaningful guidelines.

The research trajectory on the linkage between forest health and deer also compels us to recognize the critical role humans play in sustaining diverse forests and healthy herds through management, policy, and recreation decisions. Policies can help maintain populations within healthy limits, particularly given the decline in numbers of hunters (Diefenbach et al. 2005). By the same token, land managers can sustainably create young forest habitat (early successional) to improve deer conditions and engage hunters who help regulate herd density. Only by engaging all three key stakeholders—policymakers, land managers, and hunters—can we sustain and improve on various ecological services provided by forest communities over the next century.

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USING HERBICIDES TO CONTROL INTERFERING UNDERSTORIES IN ALLEGHENY HARDWOOD STANDS

1. EARLY DEVELOPMENT OF PRESCRIPTIONS

Stephen B. Horsley[1]

Insights for Managers

- **The first two decades of research into using herbicides to control understories that interfered with establishment of advance regeneration in Allegheny hardwood stands showed that time of application was critically important. Optimum dates of application were:**
  - **Hay-scented and New York fern: Early July to leaf yellowing in mid-September**
  - **Short husk grass: Early June to mid-September**
  - **Striped maple and beech: Early August to mid-September**
- **In addition to removing interfering plants, we recommended overstory treatments such as shelterwood seed cuts to ensure enough light reached the forest floor in these dense stands.**
- **Partial overstory removals disturb the forest floor, releasing grass and sedge seedbanks where present. Thus, timing herbicide treatments to follow partial overstory harvests increased control of seedbank species.**

I came to work at the Forestry Sciences Laboratory in 1973, about 10 years after harvest cutting had begun in the maturing second-growth Allegheny hardwood forest. Clearcutting had been selected as the forest regeneration technique because it seemed to have worked well in the turn of the 20th century harvests on the Allegheny Plateau. But at this time, only about half the stands regenerated to desirable species; the other half regenerated to hay-scented fern (*Dennstaedtia punctilobula*), New York fern (*Thelypteris noveboracensis*), grasses and sedges, or to shade-tolerant understory trees such as striped maple (*Acer pensylvanicum*) and American beech (*Fagus grandifolia*).

Abundant small seedlings were required to regenerate these stands. Small seedlings were typically either inadequate or absent. Instead, ground cover was of hay-scented and New York fern, grasses and sedges, or understory trees of striped maple and American beech.

We knew that deer played a role in reducing abundance of advance regeneration of desirable species and establishing unpalatable interfering vegetation, but the dynamics were not yet clear (see Horsley and Marquis 1983, Marquis 2019, Royo and Stout 2019).

Early studies (Horsley 1986) showed that interfering plants interrupted the regeneration process and had to be removed for this process to continue. The ferns regenerated with an underground stem, or rhizome; grasses and sedges regenerated from seed or rhizomes; striped maple from seed, and beech primarily from root suckers.

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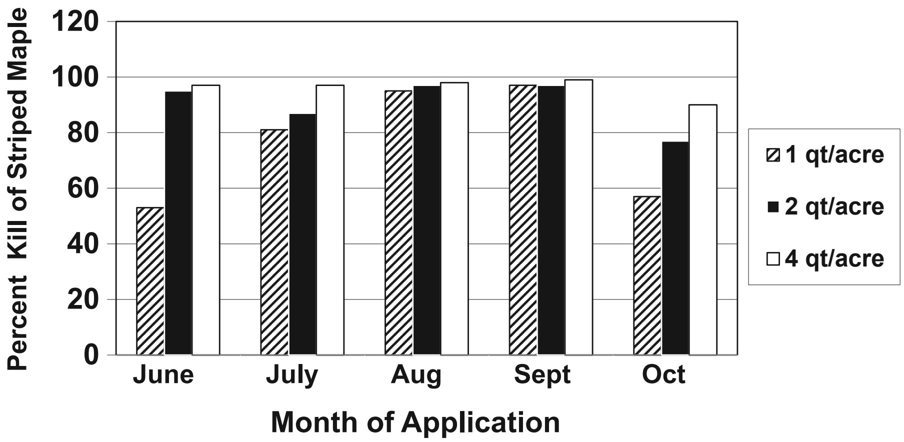

Figure 1.—Striped maple control results by rate and time of application of Roundup®.

In 1976, we began a series of studies with herbicides to develop methods to remove interfering vegetation and establish advance regeneration of desirable species. We initially worked on small plots. After tests that included prescribed fire and manual weeding showed that herbicides were far more effective and efficient, we tested several herbicides on plots with complete ground covers of fern, grass and sedge, striped maple, or beech as follows:

- Three applied rates
- A control
- Several months of application during the growing season

These studies showed that Monsanto's Roundup®[2] herbicide, a 4-pound active ingredient per gallon herbicide containing glyphosate and a surfactant (the surfactant was later marketed as Entry-2), controlled all the target species. We also learned the importance of time of herbicide application in determining the rate of application for effective control. This was particularly true at low rates of application. Our strategy was to use time of application to control the rate of herbicide application. By applying herbicide when the target species was most susceptible, we could minimize the rate of application. This was important from economic and environmental standpoints.

For example, 95 percent or better control of 1- to 5-foot striped maple could be achieved by applying 1, 2, or 4 quarts per acre of Roundup® in early August or early September (Fig. 1). But 2-4 quarts per acre were required to achieve this level of control in early June or early July. By applying Roundup® in early August or early September, the amount of herbicide could be minimized to reduce the cost of this remedial action.

The same sensitivity to time of application occurred when 1 quart per acre was applied to striped maple stems of increasing size. More than 90 percent control of trees shorter than 1 foot could be obtained with any application date between early June and early October. However, control of larger trees was strongly dependent on application time. Optimal control was achieved with early August to early September applications and was reduced when the application was made earlier or later in the year (Horsley 1981, 1982; Horsley and Bjorkbom 1983).

[2] The use of trade, firm, or corporate names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable. In addition, trade names of many of products change over time, as do the formulations available under the same names. See Ristau 2019 for results reflecting current product names.

Time effects also were related to phenology of plant development. A cool spring often delays plant development and susceptibility to Roundup® control. Likewise in the fall, when leaf yellowing begins, uptake and translocation of Roundup® declines. Applications made after this time yielded less control in all species tested. The time of leaf yellowing, mid-September in northwestern Pennsylvania, is a practical limit to Roundup® application. A high level of plant control with the 1 quart per acre rate of Roundup® could be achieved by restricting the time of application.

Optimum dates of application for the 1 quart per acre rate of Roundup® were as follows:

- Hay-scented and New York fern: Early July to leaf yellowing in mid-September
- Short husk grass: Early June to mid-September
- Striped maple and beech: Early August to mid-September

Once interfering plants were removed, the regeneration process could continue. The most important factor in the success of regeneration was the establishment of large numbers of desirable seedlings before the final removal cut. A shelterwood seed cut leaving about 60 percent overstory stocking hastened the development of large numbers of small seedlings. These seedlings did not grow much because of the overstory light limitation, but as deer impact was high, this was an advantage because small seedlings were less attractive to deer. Within 3-5 years, large numbers of seedlings usually became established though the process sometimes took longer.

Black cherry (*Prunus serotina*) and red maple (*Acer rubrum*) regeneration usually predominated in northwestern Pennsylvania stands. The speed of regeneration development depended on the basal area of black cherry taller than 8 inches diameter at breast height; stands with at least 25 square feet of black cherry basal area per acre usually developed adequate regeneration in a few years. Once adequate regeneration was developed, the remaining overstory could be removed.

Refinements in the Initial Prescription

Commercial application of Roundup® in an herbicide-shelterwood cut system began in 1979. As widespread use of these prescriptions began, I partnered with Sandy Cochran of the Pennsylvania State University forestry extension team to convene annual meetings of those using the prescriptions to share experiences and identify research or application needs. These applications used air-blast spray equipment mounted on tracked or rubber-tired vehicles. During the first 5 years, it became apparent that refinements were required. Three problems developed as a result of application techniques and subsequent shelterwood cutting in treated stands.

Inadequate Control of Ferns

Ferns were inadequately controlled in the area traversed by the vehicle carrying the sprayer; instead, "fern tracks" were formed. Apparently, the metal cleats on tracked vehicles and the sharp edges of new rubber tires broke off small segments of fern rhizome at the time of treatment, preventing translocation of Roundup® into them and creating what we referred to as fern tracks. In the second year, these ferns began to fill in the tracks. By the third year, they had moved out into the stand. In as little as 4-6 years, shelterwood cut stands were reoccupied by ferns, which prevented desirable hardwood seedlings from becoming established. Ferns also became re-established from variable numbers of small, isolated fern plants that developed from single unkilled rhizome buds, probably as a result of incomplete coverage or incomplete translocation of herbicide within the plant.

Grass and Sedge Regeneration

Following the shelterwood seed cut, the stand sometimes regenerated to grasses and sedges rather than tree seedlings. The forest floor of most Allegheny hardwood stands contains a seed bank of grasses and sedges that germinate after disturbance. The skidding activities associated with the shelterwood seed cut provided the stimulus for germination in disturbed areas. Little grass and sedge developed on undisturbed areas, even when a large seed bank was present. Most germination occurred in the growing season after disturbance with plants growing to full size in the following year; little expansion occurred after the second year. However, once grass and sedge ground cover developed, the regeneration process was slowed so dramatically that few tree seedlings became established under our conditions, which included an extremely high deer population.

Striped Maple Stems Were Resistant

Under commercial operating conditions, striped maple stems were not always controlled by Roundup® to the extent that might be predicted from small plot experiments. Stems were almost always defoliated but were not killed and refoliated the following year from unkilled axillary buds. Increasing the rate of Roundup® application from 1 to 4 quarts per acre resulted in complete striped maple kill—but at an unacceptably high cost.

Revised Solutions Using Oust® Herbicide Alone and in Combination with Roundup®

These problems generated a new round of small and medium plot experiments using residual herbicides alone and in tank mix with Roundup®. The Dupont herbicide Oust®[3], in which the active ingredient was sulfumeturon methyl, emerged from these experiments as the most useful product.

In a rate and time experiment, we applied Oust® at 2, 4, and 8 ounces per acre. Oust® gave excellent control of the ferns at 2 ounces per acre when applied between early July and early October (Fig. 2). Results were not as good and were rate-dependent outside these time constraints. Because of its residual activity in the soil, fern tracks and isolated fern plants no longer presented a problem (Horsley 1988).

Oust® alone did not adequately control mature grass plants, but it reduced the amount of grass and sedge emerging from the forest floor seed bank by 66-75 percent. When combined with Roundup® in tank mix, mature grass plants were also controlled. The study also pointed out that on sites where grass and sedge seed banks were large, herbicide alone was inadequate to reduce reinvasion of the site; steps also were required to reduce the amount of forest floor disturbance on these sites (Horsley 1990a, 1990b).

Tests on a variety of hardwood species showed that woody plants vary considerably in their sensitivity to Oust®. Striped maple and beech were not sensitive to Oust® at any rate we tested. Black cherry and white ash were very sensitive to Oust®, particularly when it was applied early in the growing season. Red maple showed little sensitivity. Damage to sensitive species decreased later in the growing season. Treating areas with black cherry regeneration late in the growing season resulted in survival of many seedlings. Adding surfactant to Oust®

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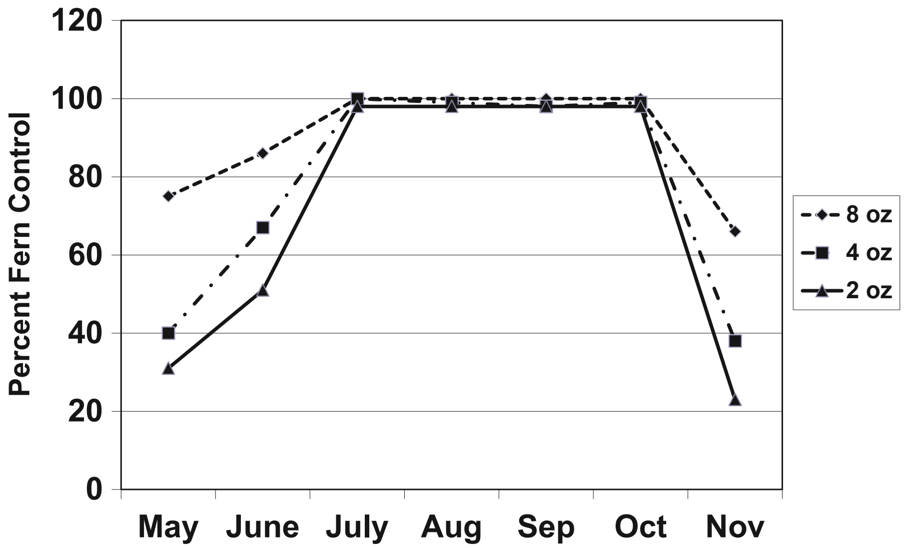

Figure 2.—Fern control results by rate and time of application of Oust®.

increased damage to all species. This research was done in partnership with Larry McCormick at Pennsylvania State University, who tested similar prescriptions in stands with a higher proportion of oak (Horsley et al. 1992).

Efforts to increase the activity of Roundup® on striped maple by adding surfactants or other adjuvants into the tank with Roundup® did not give results that were statistically different than Roundup® alone. The most important factor controlling the proportion of striped maple stems killed by Roundup® was distribution of the herbicide.

The dilemma in ground spray operations with most air-blast spray equipment in use at the time was that the sprayer volute allowed the main blast of spray to be directed to vegetation in a limited vertical space. Aiming the volute horizontally resulted in good coverage of vegetation up to about 10 feet in height; aiming the volute at an upward angle resulted in good coverage from 5-20 feet in height, but shorter vegetation was not well covered, because much of the spray was intercepted by the larger vegetation.

This problem was solved by the use of improved spray apparatus by the major forest landowners on the Allegheny Plateau. About 1987, International Paper Company (successor to Hammermill Paper Company) purchased a Friend air-blast sprayer (Friend Manufacturing, Gasport, NY) mounted on an FMC tracked vehicle. The volute on the Friend had a vertical stack of nozzles that filled the air space with spray from the ground to about 20 feet in height. This machine was set up to spray out one side. The air blast from its squirrel-cage fan shook the leaves of understory trees, resulting in good herbicide penetration and distribution, with swath width about 50 feet in brush and 70 feet in fern and grass. Exceptionally good control of short and tall vegetation in this space was obtained in commercial spray operations using a tank mix of Roundup® and Oust®. Other landowners and commercial contractors also purchased or developed new equipment for their herbicide operations.

SUMMARY

Our results have shown that two herbicides are useful in obtaining regeneration of Allegheny hardwoods on the Allegheny Plateau: Roundup® applied at the rate of 1 quart of product per acre or 1 pound active ingredient per acre; and Oust® applied at the rate of 2 ounces of product per acre or 1.5 ounces active ingredient per acre. Optimum dates of application for Roundup® were early June to mid-September for grass and sedge, early July to mid-September for ferns, and early August to mid-September for striped maple and beech. Oust® could be applied from early July to early October for ferns and for pre-emergent reduction of grasses and sedges from the forest floor seed bank. Oust® has no effect on striped maple and beech.

The Allegheny Plateau mostly has a mixture of fern, grass, striped maple, and beech, so we recommended a tank mix of Roundup® and Oust®. Where ferns or ferns and a grass and sedge seed bank are the only target species, Oust® could be used alone. Where striped maple and beech are the only target species, Roundup® alone could be used.

Usually, sites with interfering vegetation lacked adequate regeneration of desirable species, even before herbicide is applied, so we needed to take steps to obtain it before a final overstory removal cut could be made. Usually, we recommended applying the herbicide in uncut stands followed by shelterwood cutting. This left 60 percent relative density to encourage establishment of advance regeneration. Where there were large grass and sedge seed banks, steps needed to be taken to reduce disturbance to the site. This was accomplished by reversing the herbicide and shelterwood operations and doing the shelterwood seed cut first, then applying the herbicide a year or two later, after grass and sedge had germinated. Then with no further disturbance in the stand, advance regeneration could become established. We developed a third alternative that we called herbicide-delay cut-clearcut, which was also intended to reduce forest floor disturbance. It was intended for stands with less than 75 percent of full stocking, as they did not require a shelterwood seed cut.

In recent years the SILVAH science team has worked to update these guidelines. Information about more recent herbicide research can be found in Ristau (2019), and research concerning silviculture for stands affected by recent forest health challenges and ecological changes is ongoing.

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The content of this paper reflects the views of the author, who is responsible for the facts and accuracy of the information presented herein.

USING HERBICIDES TO CONTROL INTERFERING UNDERSTORIES IN ALLEGHENY HARDWOOD STANDS

2. SHARPENING THE TOOLS IN THE TOOLBOX

Todd E. Ristau[1]

Insights for Managers

Recent studies have confirmed the following guidelines for herbicide use to create conditions that are favorable for establishing and growing desirable seedlings:

- **For control of fern interference alone in Allegheny hardwood or mixed-oak forests, SILVAH recommends herbicide when more than 30 percent of regeneration plots have more than 30 percent fern interference.**
  - **If seedlings are already present, SILVAH recommends sulfometuron methyl at 2 ounces per acre in 25 gallons of water without surfactant. Surfactants in this situation cause seedling mortality.**
  - **If no seedlings are present, SILVAH recommends the same treatment as for woody interference.**
- **For woody interference in Allegheny hardwood stands, SILVAH recommends herbicide when more than 30 percent of regeneration plots have more than 30 percent high or low woody interference, or when the overstory inventory shows more than 10 square feet of basal area of interfering species in sapling and pole size classes.**
  - **For these situations, SILVAH recommends glyphosate-containing herbicide formulations at 1.5 quarts in 25 gallons of water per acre.**
  - **Timing of application is important: the best results are achieved mid-July through August.**
  - **The most effective surfactant mixed with glyphosate for control of shorter and tall striped maple was the proprietary surfactant included in Roundup Pro Max®,[2] which is labeled for forestry use.**
  - **In Allegheny hardwood stands, managers give up a cohort of established seedlings when they treat woody interference with glyphosate.**
  - **In mixed-oak forests, SILVAH recommends glyphosate to treat woody interference only in the absence of an oak seedling cohort.**

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INTRODUCTION

Dense rhizomatous herbaceous ferns such as hay-scented fern (*Dennstaedtia punctilobula*) and New York fern (*Thelypteris noveboracensis*), graminoids such as bearded shorthusk (*Brachelytrum erectum*), *Danthonia* spp., and *Carex* sp. ground cover, and woody understories of striped maple (*Acer pensylvanicum*), American beech (*Fagus grandifolia*), and sweet birch (*Betula lenta*) are found throughout the Allegheny Plateau region and beyond (Allegheny National Forest 1995, Horsley 1991). Considerable evidence suggests these ground cover layers are caused by long-term browsing by overabundant white-tailed deer (Horsley et al. 2003, Tilghman 1989). Once these plants occupy the understory, they interfere strongly with the regeneration and establishment of desirable woody species (Horsley 1993a, 1993b; Horsley and Marquis 1983).

Established methods for controlling interfering plants have been used since the 1980s (Horsley 1988b, Horsley and Bjorkbom 1983, Horsley and Marquis 1983). Earlier research in the Allegheny hardwood type showed that a tank mix of the herbicides glyphosate and sulfometuron methyl effectively, economically, and safely removes interfering plants and minimizes their impact on regeneration so desirable hardwood species can become established (Horsley 1981, 1982, 1988a, 1990a, 1990b, 1991, 1994; Horsley and Marquis 1983; McCormick et al. 1991). The herbicide application is typically associated with a shelterwood seed cut to promote the establishment of desirable woody species (Horsley and Marquis 1983). Since the early research was completed, changes in products labeled for forestry use and differences among contractors often have resulted in operational reports of unacceptable and incomplete control of the targeted species.

When USDA Forest Service scientists hosted a collaborators' meeting in the early 2000s, foresters and silviculturists suggested they have all the tools they need (herbicides, fertilizers, cutting methods, and equipment), but the tools need to be refined and reshaped for emerging problems. Inadequate striped maple control and inadequate control of ferns using Oust® were enough of a concern that the Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry funded three herbicide studies to allow us to sharpen the herbicide tool that was routinely used across that state. The research included:

- A study to evaluate the control of striped maple when imazapyr was added to the herbicide mix.
- A study of surfactants used with glyphosate to control striped maple.
- An expanded study of Oust® control of ferns and its impacts on various tree seedlings.

THE IMAZAPYR STUDY

Methods

Six 32-acre sites were chosen on the Susquehannock State Forest, all with quite uniform striped maple understories. Each site was separated into eight 4-acre treatment units. Each site included one untreated control, one scarified control (run over with equipment without spraying), and 0, 1, or 2 ounces of imazapyr applied in either July or August. A skidder-mounted mist blower was used to apply herbicides with a tank mix of 1.5 quarts of glyphosate, 2 ounces of sulfometuron methyl, and one of the imazapyr rates in 25 gallons of water per acre. Three sites were treated in 2004 and the other three in 2005. Tree species regeneration was evaluated using 10 milacre plots per treatment. Inventories were done pretreatment and 1, 2, and 5 years after treatment. Striped maple and beech control were evaluated at year 2 and

Table 1.—Percentage striped maple mortality using 1.5 quarts glyphosate and 2 ounces sulfometuron methyl alone or in combination with 1 ounce or 2 ounces imazapyr per acre. Numbers in parentheses are standard error of the mean. Values within a height class and year followed by the same letter are not significantly different at $p < 0.05$.

			1.5 quarts glyphosate and 2 ounces sulfometuron methyl					
			No imazapyr		1 ounce imazapyr		2 ounces imazapyr	
Striped maple	Control	Scarified control	July	August	July	August	July	August
			Percent mortality 2 years after treatment					
<15 ft	22.2^{a}	11.9^{a}	62.8^{b}	52.2^{bc}	63.7^{b}	55.6^{bc}	61.3^{b}	49.5^{c}
	(3.7)	(2.3)	(4.6)	(4.1)	(3.5)	(3.7)	(4.2)	(4.4)
>15 ft	17.9^{a}	3.5^{b}	65.9^{c}	57.9^{c}	61.8^{c}	67.0^{c}	72.0^{c}	51.5^{c}
	(5.6)	(1.6)	(6.2)	(7.0)	(5.7)	(7.1)	(6.4)	(6.5)
			Percent mortality 3 years after treatment					
<15 ft	29.0^{a}	18.6^{a}	88.4^{b}	72.8^{c}	65.7^{c}	70.8^{c}	67.5^{c}	75.7^{bc}
	(12.1)	(5.5)	(2.8)	(10.7)	(7.9)	(5.3)	(10.0)	(6.0)
>15 ft	12.5^{a}	4.6^{a}	62.1^{bc}	62.3^{bc}	62.3^{bc}	80.8^{b}	77.9^{bc}	65.2^{c}
	(10.0)	(3.2)	(13.9)	(8.7)	(8.7)	(10.4)	(11.2)	(14.8)

year 3 on ten 1-100th acre plots with a center coincident with the regeneration plots. All sites were fenced with electric deer exclosures to reduce deer impact on seedlings. SAS version 9.4 (SAS Institute Inc. 2011) was used to conduct all statistical analyses. See the appendix on page 55 for details.

Results

Striped maple control did not increase significantly by adding 1 or 2 ounces of imazapyr to a tank mix with glyphosate. In untreated control plots, mortality of striped maple shorter than 15 feet (shorter striped maple) was 29 percent after 3 years and was 12.5 percent for striped maple taller than 15 feet (tall striped maple) (Table 1). Percent mortality after herbicide treatment was higher for year 3 than year 2, suggesting a delayed effect for the trees to succumb to herbicide treatment (Table 1). Tall striped maple crowns are usually higher than ground spray equipment can reach; therefore, the entire crown often is not treated. Less chemical is thus absorbed and translocated. The 3-year postherbicide mortality ranged from 62 percent to 81 percent (Table 1). Shorter striped maple was best controlled in stands treated with glyphosate and sulfometuron methyl alone (88 percent mortality). Treatment in July without imazapyr resulted in significantly higher mortality than all other formulations and timing combinations, except for stands treated with 2 ounces of imazapyr in the mix applied in August (75.7 percent) (Table 1). These results showed that all formulations produced essentially the same results for shorter and tall striped maple, though average mortality was higher in some treatments including imazapyr, but none of these were statistically significant. Land managers in the region have suggested that they observe better control of all striped maple when imazapyr is included in the mix. However, results of this study do not support their observation for control of shorter striped maple and are mixed at best for tall striped maple.

Another question arose about whether applications of imazapyr had any negative or positive effects on regeneration development. Five species (American beech, black cherry, red maple, striped maple, and sweet birch) made up most of the seedling regeneration in this study. The results presented are limited to the end point of the study (5 years) (Table 2). For seedlings taller than 1 foot, only red maple showed significant differences between treatments. The 5,283 red maple seedlings per acre in stands treated with glyphosate and sulfometuron methyl

Table 2.—Seedlings present (number per acre) 5 years after treatment with herbicides including 1.5 quarts glyphosate, 2 ounces sulfometuron methyl, and 0, 1, or 2 ounces imazapyr applied in July or August. Numbers in parentheses are standard error of the mean. Values within a species row followed by the same letter are not different at p <0.05.

			1.5 quarts glyphosate and 2 ounces sulfometuron methyl					
			No imazapyr		1 ounce imazapyr		2 ounces imazapyr	
Species	Control	Scarified control	July	August	July	August	July	August
			Seedlings per acre shorter than 1 foot					
American beech	933^{a}	680^{a}	383^{a}	517^{a}	433^{a}	467^{a}	514^{a}	413^{a}
	(415)	(235)	(147)	(176)	(156)	(258)	(258)	(136)
Black cherry	44 400^{ab}	40 160^{ab}	61 933^{ab}	52 900^{ab}	56 600^{ab}	96 917^{cd}	97 343^{cd}	23 058^{bd}
	(17 254)	(7473)	(16 624)	(2 5113)	(20 665)	(25357)	(27391)	(5468)
Red maple	19 417^{a}	8860^{a}	53 300^{ab}	63 983^{b}	67 250^{b}	42 533^{ac}	76 500^{bc}	16 949^{acd}
	(10 022)	(4242)	(24 831)	(30 192)	(30 582)	(18156)	(32659)	(6458)
Striped maple	1517^{a}	2760^{a}	7017^{b}	3900^{ab}	3567^{ab}	3000^{ac}	2986^{abc}	3396^{ac}
	(389)	(1139)	(2218)	(1534)	(1031)	(836)	(1412)	(2427)
Sweet birch	33^{a}	580^{ab}	617^{b}	2133^{bc}	1017 ^{abc}	1050^{abc}	1314^{abc}	2651^{c}
	(33)	(580)	(430)	(1726)	(653)	(542)	(1134)	(1439)
			Seedlings per acre taller than 1 foot					
American beech	1400^{a}	1760^{a}	167^{a}	850^{a}	283^{a}	400^{a}	286^{a}	953^{a}
	(658)	(609)	(92)	(304)	(207)	(181)	(167)	(555)
Black cherry	83^{a}	480^{a}	1150^{a}	150^{a}	1183^{a}	1150^{a}	600^{a}	204^{a}
	(83)	(455)	(798)	(131)	(751)	(931)	(600)	(63)
Red maple	267^{a}	100^{a}	867 ^{ab}	5283^{b}	1067^{abc}	1350^{abc}	686^{c}	3696^{abc}
	(247)	(77)	(576)	(4375)	(648)	(1054)	(686)	(3168)
Striped maple	567^{a}	480^{a}	1000^{a}	550^{a}	567^{a}	533^{a}	529^{a}	467^{a}
	(128)	(229)	(515)	(293)	(238)	(217)	(219)	(101)
Sweet birch		180^{b}	733^{abc}	217^{ab}	633^{abc}	567^{abc}	543^{abc}	1571^{c}
	0^{a}	(156)	(733)	(217)	(633)	(528)	(543)	(966)

without imazapyr was the greatest number of all stems taller than 1 foot. In general, removing striped maple and American beech increased seedling development of the more desirable species. Black cherry seedlings shorter than 1 foot averaged 44,000 seedlings per acre on control plots but ranged from 52,900 to 97,343 stems per acre across all treated plots, except for plots treated with 2 ounces of imazapyr in August, when there were 23,058. Red maple had a similar response with 19,417 seedlings shorter than 1 foot on control plots and ranged from 42,533 to 76,500 stems per acre on treated plots, except for the 2-ounce imazapyr treatment in August, which had 16,949 stems per acre. Imazapyr had no lasting negative impact, except when 2 ounces per acre were applied in August. This resulted in fewer red maple and black cherry seedlings. None of the differences were significant for seedlings taller than 1 foot.

THE SURFACTANT STUDY

Methods

Six 32-acre sites were chosen in three Pennsylvania State Forests, two on the Susquehannock State Forest, two on Elk State Forest, and two on the Moshannon State Forest. All herbicide treatments to striped maple dominated understories included 1.5 quarts of glyphosate and 2 ounces of sulfometuron methyl per acre. An untreated control plot, an herbicide without surfactant treatment and herbicide treatments with six different surfactants were made at each site. The midpoint of the label-suggested rate range (shown in parentheses after each surfactant's name) was used for each surfactant added to the tank mix. Surfactants used included Cide-Kick II™ (12 ounces), Kingpin (12 ounces), Surf-AC® 910 (6 ounces), Chemsurf ™ 90 (10 ounces), Monsanto's Roundup PROMAX® proprietary formulation (in mix), and Liberate® with LECI-TECH® (12 ounces). Tree species regeneration was evaluated using 20 milacre plots per treatment. Striped maple and beech control were evaluated on five 1-100th acre plots located randomly within each treatment area for 2 years after treatment. Areas were not fenced but had relatively low deer impacts. SAS version 9.4 (SAS Institute 2011) was used to condut statistical analyses. See the appendix on page 55 for details.

Results

Early research on herbicide to control striped maple used glyphosate as Roundup®, which contained a proprietary surfactant known as MON0818, later marketed as Entry 2. It was a polyethoxylated tallow amine that was implicated in negative impacts on amphibians. Changes in formulation led to use of glyphosate products without a surfactant. Managers began using various surfactants, but no research had been conducted into which ones worked best. The surfactant study conducted here tested for differences between the six surfactants and herbicide without surfactant. Like the arsenal study, the study detected a background mortality of 12 percent in smaller striped maple (shorter than 15 feet) and 4 percent in large striped maple (taller than 15 feet). The proprietary surfactant in Roundup ProMax® is different than original Roundup® and outperformed all other surfactants except KingPin in shorter striped maple (Fig. 1). Glyphosate with no surfactant resulted in 50 percent mortality in shorter striped maple. All other surfactants—Chemsurf ™ 90, Cide-Kick II™, Liberate®, and Surf-AC® 910—resulted in about 60 percent mortality after 2 years (Fig. 1A). For tall striped maple, Roundup® resulted in the best control, but was only statistically better than Surf-AC® 910 (Fig. 1B). Tall striped maple mortality was 20–25 percent with all surfactants except Roundup®, which was 40 percent. There was some concern about whether these surfactants changed the efficacy of glyphosate on American beech mortality. Mortality was 90 percent or higher for small American beech, except for Cide-Kick II™, which resulted in 60 percent mortality on average, lower than no surfactant at all. Taller American beech were not well represented in the data, and statistical tests could not be conducted. Results verify that glyphosate is still an effective tool in the toolbox for striped maple control (perhaps as Roundup PROMAX®, which is now labeled for forestry use).

REVISITING THE OUST® PRESCRIPTION

Methods

Five sites that fit the broad-scale criteria of having a fern interference problem and presence of seedlings beneath the fern were obtained from the Clear Creek, Cornplanter, Elk, Moshannon, and Susquehannock Districts of the Pennsylvania Bureau of Forestry. The sites selected were reasonably uniform in overstory basal area, ground cover, regeneration, and site conditions. Site limitations such as excessively wet or rocky soils were not permitted. Within each site, 24 treatment plots were selected by walking through the general area of the stand looking for locations with at least 5 seedlings in a dominating fern cover area. The 24 treatment plots were established in groups of 4 to allow for 4 rates of herbicide (0, 2, 3, or 4 ounces per acre), with the 6 groups representing different treatment times (June, July, August 2013 or 2014). Milacre plot centers were established within a 10-foot × 10-foot treatment area. Treatment times and rates were assigned randomly. A garden sprayer was used to apply the herbicide. Plots were not fenced and experienced browsing, but it was not consistent or widespread. Before treatment and full fern expansion (May 15-30), plant inventories were conducted on milacre

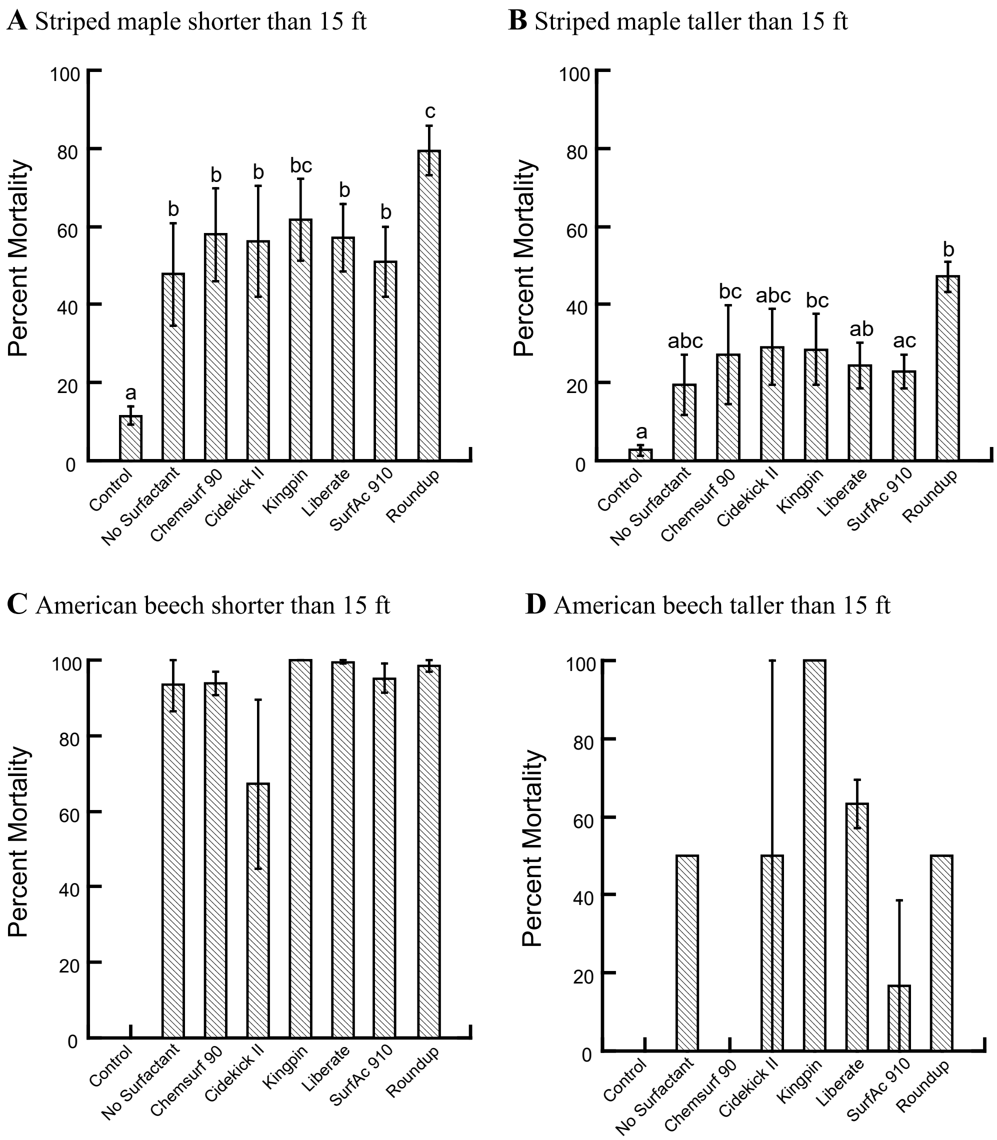

Figure 1.—Mortality, as a percentage, following herbicide application using different surfactants with glyphosate to control striped maple and American beech after 2 years. Bars followed by the same letter are not significant at $p < 0.05$. Too few data were available for American beech to make statistical comparisons.

plots counting all tree seedlings by species and estimating percent of plot covered by broad classes of herbaceous plants, including the targeted fern species. Inventories were repeated 1 and 2 years after treatment to assess fern control and impacts on nontarget species. SAS version 9.4 (SAS Institute Inc. 2011) was used to conduct statistical analyses. See the appendix on page 55 for details.

Results

When the interfering plant problem species is rhizomatous fern cover in the presence of desirable advance regeneration, sulfometuron methyl at 2 ounces per acre is the recommended treatment (Horsley 1988b), generally applied in late August or September. Earlier research was limited geographically, and the current study expanded the region and the species that were evaluated. The three rates tested in this revisited study all reduced hay-scented fern coverage in the first year (Table 3). After 2 years, fern cover recovered substantially from 11.4 to 13.8 percent with September sulfometuron methyl treatments at all 3 rates. July

Table 3.—Percentage cover of herbaceous plants by time and rate of Oust® application. Values in parentheses are standard error of the mean. Numbers are from 10 replicates throughout north-central Pennsylvania. Significant ($p < 0.05$) pairwise differences between pretreatment and post-treatment are indicated in bold. Rates and times showed no significant differences. Numbers in parentheses are standard error of the mean.

		Percent cover by species encountered on study plots											
		July (ounces Oust® /acre)				August (ounces Oust® /acre)				September (ounces Oust® /acre)			
	Year	0	2	3	4	0	2	3	4	0	2	3	4
Hay-scented fern	Pre	48.8	41.4	40.1	44.7	40.9	42.5	45.7	44.3	52.7	48.1	46.5	49.4
		(5.7)	(4.6)	(5.0)	(6.3)	(5.0)	(4.3)	(4.6)	(5.0)	(3.8)	(4.8)	(5.0)	(4.8)
	1 year	67.1	**0.4**	**0.3**	**0.0**	67.0	**0.6**	**0.5**	**0.4**	73.3	**1.9**	**2.9**	**1.8**
		(5.6)	**(0.2)**	**(0.1)**	**(0.0)**	(6.1)	**(0.2)**	**(0.2)**	**(0.2)**	(3.5)	**(0.6)**	**(1.1)**	**(0.6)**
	2 year	64.9	**1.0**	**0.7**	**0.3**	60.7	**1.4**	**2.2**	**1.3**	64.2	**11.4**	**12.3**	**13.7**
		(4.4)	**(0.3)**	**(0.3)**	**(0.1)**	(6.1)	**(0.5)**	**(1.0)**	**(0.5)**	(4.2)	**(2.9)**	**(4.0)**	**(4.2)**
Lycopodium spp.	Pre	1.8	3.2	4.5	3.9	1.1	5.1	6.6	2.6	8.4	2.6	0.6	2.9
		(1.6)	(3.2)	(3.7)	(3.9)	(1.1)	(4.5)	(4.8)	(2.6)	(5.4)	(1.5)	(0.5)	(2.4)
	1 year	3.8	1.6	4.5	4.3	0.1	5.1	9.2	3.2	8.7	5.3	1.3	4.3
		(2.6)	(1.2)	(3.4)	(4.2)	(0.1)	(4.2)	(5.3)	(3.2)	(4.7)	(3.4)	(1.3)	(3.3)
	2 year	1.8	1.9	4.7	2.9	1.1	4.7	6.8	3.3	7.8	6.9	0.8	4.8
		(1.4)	(1.3)	(3.5)	(2.8)	(1.1)	(4.4)	(3.9)	(3.0)	(4.2)	(4.3)	(0.8)	(3.9)
Graminoids	Pre	1.0	1.4	1.2	0.7	0.6	1.6	1.6	3.5	1.2	0.7	1.3	1.4
		(0.4)	(0.8)	(0.6)	(0.3)	(0.2)	(0.6)	(0.6)	(2.6)	(0.6)	(0.4)	(0.8)	(0.4)
	1 year	1.3	1.9	1.2	0.6	1.1	2.6	1.7	1.9	0.9	1.2	1.5	1.7
		(0.6)	(0.9)	(0.4)	(0.2)	(0.5)	(1.3)	(0.6)	(0.9)	(0.3)	(0.8)	(1.0)	(0.9)
	2 year	1.8	0.6	1.4	1.7	0.8	3.9	6.2	2.5	1.8	1.8	2.8	1.9
		(0.9)	(0.2)	(0.4)	(1.1)	(0.3)	(1.6)	(2.8)	(1.2)	(1.1)	(1.1)	(1.5)	(0.9)
Rubus spp.	Pre	2.2	1.7	2.1	2.3	3.6	2.7	4.3	3.0	1.6	4.5	3.6	0.8
		(1.1)	(0.8)	(1.1)	(1.1)	(1.2)	(1.0)	(1.5)	(1.2)	(0.5)	(3.1)	(1.5)	(0.5)
	1 year	**9.5**	**0.1**	0.7	0.7	6.7	4.4	2.7	2.8	3.9	1.0	0.3	0.3
		(3.0)	**(0.1)**	(0.5)	(0.3)	(2.0)	(2.1)	(1.5)	(1.4)	(1.5)	(0.6)	(0.2)	(0.2)
	2 year	**9.2**	1.6	2.9	1.7	**10.2**	5.2	1.6	3.7	**4.9**	1.3	2.9	1.6
		(2.6)	(0.9)	(1.6)	(0.9)	**(4.1)**	(2.0)	(0.7)	(1.5)	**(1.8)**	(0.6)	(1.3)	(0.8)
Other herbaceous	Pre	8.6	6.5	5.2	5.4	5.2	4.1	5.1	5.6	4.9	4.2	6.2	5.9
		(2.7)	(2.2)	(1.4)	(2.1)	(1.3)	(1.3)	(1.1)	(1.5)	(1.1)	(1.1)	(1.6)	(1.5)
	1 year	7.5	3.4	5.2	2.6	7.8	5.4	4.8	4.4	9.7	2.2	4.9	2.8
		(2.2)	(1.0)	(1.5)	(1.2)	(2.5)	(1.5)	(1.2)	(1.7)	(2.6)	(0.6)	(2.2)	(0.9)
	2 year	8.4	6.7	5.9	6.1	11.6	11.9	7.7	8.4	9.8	5.7	5.1	3.9
		(1.9)	(2.2)	(2.0)	(1.8)	(4.8)	(3.7)	(2.3)	(2.9)	(2.6)	(1.8)	(1.6)	(1.5)

and August treatments had cover that ranged from 0.3 to 2.2 percent cover after 2 years. Graminoids (grasses and sedges), Lycopodium species, and flowering plants collectively were all unaffected by sulfometuron methyl at any rate or timing combination (Table 3). Without sulfometuron methyl *Rubus* percent cover significantly increased over time. Various rate and timing combinations reduced *Rubus* cover, though only treatment in July with 2 ounces of sulfometuron methyl per acre differed significantly (Table 3).

Sulfometuron methyl often is used to control ferns when desirable seedlings are present among the fern. The 2-year results of this study showed that very few species were negatively affected by treatment with sulfometuron methyl. One species, downy serviceberry (*Amelanchier arborea*), had lower cover with all rates and times of treatment with sulfometuron methyl (Table 4). The effect was greater later in the season than early in the growing season.

Table 4.—Stem density (thousands of stems per acre) by time and rate of Oust® application. Values in parentheses are standard error of the mean. Numbers are from ten replicates throughout north-central Pennsylvania. Treatments did not differ significantly. Differences from control plots within a treatment month are shown in bold type.

	Year	Thousands of stems per acre found on study plots											
		July (ounces of Oust® /acre)				August (ounces of Oust® /acre)				September (ounces of Oust® /acre)			
		0	2	3	4	0	2	3	4	0	2	3	4
Red maple	Pre	16.4 (4.0)	18.7 (4.7)	24.0 (4.5)	17.6 (3.2)	17.3 (3.0)	15.6 (3.4)	13.2 (3.4)	23.2 (6.2)	20.2 (6.3)	21.3 (5.2)	16.1 (3.4)	15.8 (3.8)
	1 year	14.9 (2.7)	21.6 (5.2)	22.4 (5.2)	18.1 (4.7)	16.5 (3.8)	15.1 (3.7)	16.8 (6.9)	18.7 (4.1)	20.7 (6.9)	24.2 (6.9)	18.4 (4.0)	19.0 (5.8)
	2 year	11.6 (2.7)	16.6 (3.6)	18.9 (3.7)	15.3 (2.8)	11.6 (2.2)	11.8 (2.6)	10.3 (2.8)	15.8 (3.2)	14.6 (4.5)	20.3 (6.2)	15.7 (3.0)	14.8 (4.1)
Sugar maple	Pre	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)	0.5 (0.3)	0.6 (0.6)	0.1 (0.1)	0.0 (0.0)	0.2 (0.1)	0.3 (0.2)	0.1 (0.1)	0.0 (0.0)
	1 year	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)	0.4 (0.3)	0.4 (0.3)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)	0.1 (0.1)
	2 year	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.4 (0.3)	0.3 (0.3)	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)
Serviceberry	Pre	3.4 (1.6)	1.3 (0.6)	2.7 (1.1)	1.2 (0.5)	7.2 (3.2)	2.1 (1.0)	2.2 (1.1)	2.2 (0.8)	3.5 (1.6)	3.7 (2.2)	1.7 (0.9)	2.6 (1.5)
	1 year	2.9 (0.9)	**1.2 (0.5)**	**1.3 (1.0)**	**0.7 (0.4)**	4.5 (1.6)	**0.4 (0.3)**	**0.2 (0.1)**	**0.6 (0.2)**	4.3 (1.6)	**0.4** (0.2)	0.2 (0.1)	0.6 (0.6)
	2 year	3.2 (1.2)	**1.2 (0.6)**	**1.7 (0.8)**	**1.2 (0.8)**	5.3 (2.0)	**0.8 (0.3)**	**0.8 (0.3)**	**1.2 (0.5)**	4.2 (1.4)	**0.9 (0.5)**	**0.7 (0.3)**	**1.1 (0.9)**
Black birch	Pre	0.4 (0.2)	0.5 (0.4)	0.2 (0.1)	0.4 (0.2)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.5 (0.3)	0.0 (0.0)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
	1 year	0.3 (0.1)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)	0.1 (0.1)
	2 year	0.2 (0.1)	0.4 (0.2)	0.1 (0.1)	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.3 (0.3)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
American beech	Pre	0.3 (0.2)	0.3 (0.3)	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)	0.2 (0.2)	0.0 (0.0)	0.2 (0.1)	0.0 (0.0)	0.2 (0.1)	0.1 (0.1)	0.2 (0.2)
	1 year	0.4 (0.3)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)
	2 year	0.6 (0.4)	0.2 (0.2)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	0.0 (0.0)	0.2 (0.1)	0.2 (0.2)	0.2 (0.2)

continued

Table 4.—continued

	Year	Thousands of stems per acre found on study plots											
		July (ounces of Oust® /acre)				August (ounces of Oust® /acre)				September (ounces of Oust® /acre)			
		0	2	3	4	0	2	3	4	0	2	3	4
Yellow-poplar	Pre	0.3 (0.2)	0.9 (0.7)	0.9 (0.6)	0.5 (0.3)	0.4 (0.3)	0.5 (0.3)	1.0 (0.6)	1.1 (0.6)	1.0 (0.9)	1.0 (0.6)	0.6 (0.5)	0.9 (0.9)
	1 year	0.5 (0.3)	0.8 (0.5)	1.1 (0.6)	0.5 (0.4)	0.3 (0.2)	0.4 (0.3)	1.1 (0.6)	0.8 (0.5)	0.6 (0.6)	0.9 (0.5)	0.5 (0.3)	0.7 (0.7)
	2 year	0.4 (0.3)	1.3 (0.9)	1.1 (0.7)	0.6 (0.4)	0.4 (0.3)	0.6 (0.5)	0.9 (0.5)	0.8 (0.4)	0.8 (0.8)	0.9 (0.5)	0.4 (0.2)	0.7 (0.7)
Cucumbertree	Pre	0.4 (0.2)	0.5 (0.3)	0.3 (0.2)	0.5 (0.3)	0.4 (0.2)	0.4 (0.2)	0.6 (0.2)	0.1 (0.1)	0.5 (0.2)	0.6 (0.3)	0.3 (0.2)	0.3 (0.2)
	1 year	0.4 (0.1)	0.5 (0.3)	0.4 (0.2)	0.3 (0.1)	0.4 (0.2)	0.6 (0.3)	0.3 (0.1)	0.1 (0.1)	0.5 (0.2)	0.5 (0.2)	0.2 (0.1)	0.2 (0.1)
	2 year	0.4 (0.2)	0.4 (0.2)	0.3 (0.1)	0.6 (0.2)	0.7 (0.5)	0.3 (0.2)	0.6 (0.2)	0.1 (0.1)	0.6 (0.2)	0.3 (0.1)	0.2 (0.1)	0.2 (0.1)
Pin cherry	Pre	0.2 (0.2)	0.3 (0.2)	0.2 (0.1)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)
	1 year	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	2 year	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
Black cherry	Pre	2.9 (1.2)	3.3 (1.2)	5.8 (3.0)	2.4 (0.8)	8.1 (3.8)	10.6 (6.9)	11.0 (6.0)	10.0 (5.4)	5.4 (1.9)	9.7 (5.0)	7.5 (3.3)	6.6 (4.1)
	1 year	2.3 (0.8)	2.0 (1.0)	2.8 (1.2)	1.4 (0.5)	6.4 (2.5)	5.3 (3.1)	4.6 (2.2)	4.3 (2.0)	4.9 (1.5)	5.4 (2.7)	6.9 (3.1)	2.9 (1.8)
	2 year	1.6 (0.6)	2.2 (0.9)	3.3 (1.2)	1.4 (0.5)	4.8 (1.5)	4.2 (2.0)	4.6 (2.2)	4.4 (2.2)	2.8 (0.8)	4.5 (2.7)	4.4 (1.6)	2.2 (1.3)
Red oak	Pre	5.0 (1.4)	5.2 (1.6)	6.3 (2.0)	6.7 (2.0)	6.6 (2.1)	4.7 (1.2)	5.5 (1.9)	6.8 (2.0)	7.5 (2.6)	4.5 (1.5)	5.8 (2.3)	8.4 (5.2)
	1 year	5.2 (1.3)	6.1 (1.7)	7.8 (2.2)	6.1 (1.5)	5.9 (2.2)	4.8 (1.4)	4.8 (1.5)	5.2 (1.4)	6.2 (2.3)	5.1 (1.9)	6.3 (2.0)	7.2 (3.4)
	2 year	4.5 (1.4)	5.9 (1.7)	8.2 (2.3)	5.7 (1.5)	5.7 (2.1)	4.7 (1.4)	4.3 (1.4)	5.2 (1.4)	6.3 (2.2)	5.3 (1.6)	7.2 (2.3)	6.7 (3.2)

SUMMARY OF ALL STUDIES

Herbicides remain an important tool in the regeneration toolbox that landowners have at their disposal. Several years of changing product labeling on glyphosate products resulted in varying surfactants being used without research guidance. Striped maple have grown into larger size classes since initial research was conducted on the Allegheny Plateau, and treatment of the entire crown with chemicals has become more difficult. Surfactants and altered rates and timing of herbicide application for striped maple control have also had mixed results. Managers began adding imazapyr in hopes of improving striped maple control. Use of imazapyr is not detrimental to seedling development and does not improve taller striped maple control. The results presented here show that Roundup PROMAX® herbicide, including its proprietary surfactant, achieves the best control of all striped maple.

Sulfometuron methyl, or Oust® XP herbicide, controls ferns effectively. Past research suggested the later the treatment the better, but the results shown here suggest that July or August application with 2 or 3 ounces of product per acre controls ferns best and results in less regrowth. Nontargeted species and tree species are not affected except for serviceberry, which was reduced by sulfometuron methyl application. All sulfometuron methyl applications with a goal of protecting seedlings should not use a surfactant. Early work done showed that use of a surfactant in the mix with sulfometuron methyl damaged most hardwood species. Oust® is still an effective tool.

Silvicultural use of herbicides as part of the regeneration process continues to control unwanted vegetation and thus reduce low shade on developing seedlings. This research provides expanded guidance on when to use the tools most effectively and is applicable in Pennsylvania and other states (Brose et al. 2008, Marquis 1994, Marquis et al. 1992).

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APPENDIX: Statistical Methods

Imazapyr Study

SAS version 9.4 (SAS Institute Inc. 2011) was used for all statistical analyses. Generalized linear mixed models using PROC MIXED were used to model the effects of year, site, rate, and timing of herbicide application on target variables. In all models, site was considered a random effect; year, rate, and timing were fixed effects. Year was considered a repeated measure (Littell et al. 2006). All models used the restricted maximum-likelihood (REML) method and the Kenward-Roger procedure to adjust the denominator degrees of freedom (SAS Institute 2011). Tukey-Kramer tests in the LSMEANS option of the MIXED procedure were used to conduct post-hoc tests to identify years with significant differences between control and experimental treatments.

Surfactant Study

Generalized linear mixed models using PROC MIXED were used to model the effects of site and surfactant used with herbicide application on target variables. In all models, site was considered a random effect; surfactant was a fixed effect. Year was considered a repeated measure (Littell et al. 2006). All models used the REML method and the Kenward-Roger procedure to adjust the denominator degrees of freedom (SAS Institute 2011). Tukey-Kramer tests in the LSMEANS option of the MIXED procedure were used to conduct post-hoc tests to identify differences between treatments.

Revisiting the Oust® Prescription

Generalized linear mixed models using PROC MIXED were used to model the effects of year, site, rate, and timing of herbicide application on target variables. In all models, site was considered a random effect; year, rate, and timing were fixed effects. Year was considered a repeated measure (Littell et al. 2006). All models used the REML method and the Kenward-Roger procedure to adjust the denominator degrees of freedom (SAS Institute 2011). Tukey-Kramer tests in the LSMEANS option of the MIXED procedure were used to conduct post-hoc tests to identify years with significant differences between control and experimental treatments.

EXPANDING THE SILVAH DECISION SUPPORT SYSTEM TO BE APPLICABLE TO THE MIXED-OAK FORESTS OF THE MID-ATLANTIC REGION

Patrick H. Brose[1]

Insights for Managers

Using SILVAH correctly to manage mixed-oak forests requires thoroughness and attention to detail. Key recommendations for its correct use include:

- **Conduct a complete inventory of the stand. SILVAH uses data collected from the overstory and understory strata to arrive at a recommended prescription. Incomplete or inaccurate inventory data will either cause SILVAH to not run or produce poor results.**
- **Pay attention to default settings. Ensuring the default settings are correct is as important as a quality inventory. These settings appear as user-defined choices such as desired forest type, favoring oak, starting a regeneration sequence, and wanting residuals post-harvest. Don't accept the default settings without question; rather, examine them in the context of the stand's conditions and your intentions for that stand.**
- **Obey the two "laws" of oak silviculture (Loftis 2004): To successfully regenerate mixed-oak stands, there must be adequate sources of competitive oak advanced reproduction and an adequate, timely release. Sander (1972) defined a competitive oak as being ≥4.5 feet tall; recent research is verifying that size (Brose et al. in press), so there must be an adequate density of oak stems 4-5 feet tall before the final harvest to meet future oak stocking objectives. Those oak stems must be exposed to at least 80 percent full sunlight via a final harvest to grow vigorously and successfully compete against the reproduction of other tree species (Miller et al. 2006).**
- **Remember young oak stands (ages 1-15 years). These stands need to be checked at least twice (Brose et al. 2008). Check them at age 3-5 years to determine if a competition problem is developing and take any necessary remedial action. Check them again at age 10-15 years to determine whether crop tree management is warranted to keep the dominant and codominant oak saplings in those canopy positions.**

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INTRODUCTION

In late 1999, the Pennsylvania Bureau of Forestry entered into a partnership with the USDA Forest Service's Northern Research Station to revise the SILVAH decision support system so that it would be more applicable to mixed-oak (*Quercus* spp.) forests. To expedite the revisions, the two agencies organized a committee of scientists and experienced field foresters who used relevant research results from other regions to devise interim inventory criteria and prescriptions. This approach accelerated the development process and facilitated acceptance of the interim guidelines in just a few years. This chapter describes in detail the work of that committee as well as science delivery efforts since the early 2000s that have resulted in an improved version of SILVAH that is applicable to mixed-oak forests and has been adopted entirely or in part in by several states in or bordering the mid-Atlantic region.

SILVAH, originally an acronym for Silviculture of Allegheny Hardwoods, is a systematic approach to silvicultural prescription development based on inventory and analysis of stand data. SILVAH began in northwestern Pennsylvania in 1967 when forest managers organized a Society of American Foresters meeting to examine regeneration failures that were, in their opinion, too common (≈50 percent) in the local maturing second-growth Allegheny hardwood and northern hardwood forests. They invited Ben Roach, a research assistant director of the USDA Forest Service's Northeastern Forest Experiment Station, to attend and participate. Managers considered the relative importance of seed production, soil and site factors, competing and interfering vegetation, and browsing by white-tailed deer (*Odocoileus virginianus*) as possible causes of the failures. Shortly thereafter, Roach assigned David Marquis to the Irvine, PA, laboratory and helped him recruit scientists of various disciplines from around the region to explore the factors that were leading to regeneration failures. By 1976 the Irvine research laboratory had accumulated enough results that it joined with the local Pennsylvania State University extension forester, Sandy Cochran, to offer 1-day training sessions to share those results with practicing foresters. The foresters readily adopted the lab's findings and recommendations, and the 50 percent regeneration failure rate in Allegheny hardwoods shrank to 10 percent in just a few years.

While SILVAH was being readily accepted and successfully used in the Allegheny and northern hardwood forest types, it offered little guidance in the expansive mixed-oak (*Quercus* spp.) forests and was not widely used by foresters working in that forest type. When the Pennsylvania Bureau of Forestry (PBF) sought third-party certification from the Forest Stewardship Council (FSC) in the late 1990s, FSC commended the structured framework of SILVAH and its success in regenerating Allegheny and northern hardwood forests and recommended its expansion to mixed-oak forests. The objective of this chapter is to tell the story of that expansion: how it occurred, the organizations and people involved, the obstacles encountered, how they were overcome, and the current status of the oak module of the SILVAH decision support system.

OAK REGENERATION STOCKING CRITERIA

In January 2000, Gary Rutherford, the PBF silviculture section chief, convened a committee of scientists and managers to develop a plan to implement the FSC recommendation. The committee included scientists from Forest Service research labs at Irvine, PA, and Morgantown, WV; faculty from Pennsylvania State University; and experienced field foresters from the Allegheny National Forest, PBF, and forest industry. The initial meeting focused on determining which species and species groups to add to SILVAH, what constituted a stocked plot for those additions, and how their stocking criteria should vary by deer impact and site quality. SILVAH uses the stocked plot concept to combine the key regeneration attributes of seedling density and seedling height. A stocked plot is defined as a regeneration inventory plot

Table 1.—Initial changes made by the SILVAH revision committee in 2000 to the size and regeneration plot stocking criteria of oak seedlings. The three-number sequence for the competitive oak seedling category represent the low, medium, and high site classes of the Pennsylvania Bureau of Forestry. The asterisks (*) denote weighted stem counts as oak seedlings more than 1 foot tall were counted twice.

		Deer Impact Level (Marquis and others 1992)				
Seedling Category	Height (feet)	1	2	3	4	5
				Before 2000		
Small oak	0.2 to 4.5	10*	20*	30*	40*	60*
Large oak	>4.5	1	1	1	1	1
				After 2000		
New oak	<0.5	25	25	50	100	200
Estblished oak	0.5 to 3.0	12	12	25	50	100
Competitive oak	>3.0	1, 2, or 3	1, 2, or 3	1, 2, or 3	1, 2, or 3	1, 2, or 3

that contains enough seedlings of a given species and size that one of those seedlings will likely occupy that plot in the next stand after a final harvest. SILVAH uses the proportion of stocked plots in a stand as a major factor to develop the recommended silvicultural prescription.

SILVAH 5.0, the version in use in 2000, categorized oak seedlings as large or small (Table 1; Marquis et al. 1992). Large oak seedlings were >4.5 feet tall and small oak seedlings were <4.5 feet tall. Stocking criteria for these two sizes of oak seedlings were one large oak and 10-60 small oaks per plot, depending on the deer impact. Because these criteria were virtually never found in oak stands, SILVAH would recommend defer cut. In the rare instances that oak stands had 70 percent of their regeneration plots stocked with adequate numbers of large or small oak, SILVAH would recommend a clearcut—complete overstory removal. The committee felt that the height and plot stocking criteria were incorrect, overlooked the root-centric growth strategy of oak seedlings (Brose 2011a), and ignored the influence of site quality (Minckler and Woerheide 1965, Trimble 1973). Additionally, the two most common oak prescriptions—defer cut and clearcut—were single-treatment prescriptions and did not include the sequencing of multiple oak regeneration practices such as the shelterwood-burn technique or the herbicide shelterwood method that had been recently developed (Brose et al. 1999, Loftis 1990a).

Because of programming limitations in SILVAH at the time (code was written in Fortran 77 and used a DOS interface), the committee considered all oak seedlings and sprouts together as "oak" regardless of species. They also created three groups of oak reproduction—competitive, established, and new—based on height or root collar diameter (RCD). Competitive oak were >3 feet tall or had RCDs >0.75 inch. These were considered large enough to dominate a regeneration plot by crown closure of a new stand (approximately 10-15 years post-harvest). Established oak were 0.5-3 feet tall or had RCDs of 0.25-0.75 inch. Oak reproduction of this size class was considered large enough to survive silvicultural operations, including growing-season prescribed fire, and sprout afterward. They were also considered to be competitive on low-quality sites (oak site index$_{50}$ <65 feet). New oak were <0.5 feet tall or had RCDs <0.25 inch. Reproduction of this size could not sprout after a growing-season prescribed fire or other intense silvicultural operations. Oak seedlings of this size need favorable growing conditions and ample time to grow into established seedlings.

To determine the stocking criteria for competitive, established, and new oak, the committee had to define a mature oak forest. To do this, the committee used overstory inventory data collected from 54 mature undisturbed oak stands scattered across Pennsylvania, West Virginia, and southern Ohio to determine the average attributes of an oak stand. The data showed that

Table 2.—Dominance probabilities at age 20* for oak seedlings by site index for southern Missouri (MO) and western North Carolina (NC). The Missouri probabilities are averages calculated across all aspects from Sander and others (1984) while the NC probabilities are taken directly from Loftis (1990).

Basal	Oak Site Index (height in feet at age 50)					
(inches)	50(MO)	60(MO)	70(MO)	70(NC)	80(NC)	90(NC)
0.1				0.01	0.00	0.00
0.2	0.01	0.01	0.00	0.02	0.01	0.00
0.3				0.04	0.02	0.01
0.4				0.06	0.03	0.01
0.5	0.16	0.15	0.03	0.09	0.04	0.02
0.6				0.13	0.06	0.03
0.7				0.17	0.09	0.04
0.8				0.21	0.12	0.06
0.9				0.25	0.15	0.08
1.0	0.41	0.37	0.12	0.29	0.18	0.11
1.1 to 1.5	0.58	0.50	0.19	0.38	0.29	0.19
1.6 to 2.0	0.68	0.73	0.28	0.46	0.41	0.34

* The likelihood that a seedling of a given basal diameter at the time of overstory removal will grow to be in a dominant or codominant crown position when the next stand is 20 years old.

the average oak stand was 80 years old, had 250 trees per acre, 120 square feet of basal area, and 100 percent stocking. Of the 250 trees, only 60 were in the main canopy (dominants or codominants), and 43 were oak. These 43 oaks accounted for 56 percent of stand stocking. These two numbers—43 mature oak per acre and 56 percent stocking—represented the desired future condition, i.e., the primary components of the new "oak stand" created by a regeneration prescription.

With the goal identified (43 mature oaks per acre and 56 percent oak stocking at age 80), the committee used 3 long-term studies (Loftis 1990b, Sander et al. 1984, Ward and Stephens 1994) to determine how many oak seedlings were needed on a 6-foot radius regeneration plot at the time of the final harvest (age 0 years) to constitute a stocked plot. Ward and Stephens (1994) reported the crown position retention rates for northern red oak (*Quercus rubra*) from age 25 to 85 in mixed hardwood stands in Connecticut. They showed that 30-35 percent of the dominant and codominant oaks at age 25 would still be in those crown positions at age 85. The others would either slip to intermediate or suppressed canopy positions or die. Also, they showed that only 5 percent of the intermediate or suppressed northern red oaks at age 25 would move up to dominant or codominant canopy positions by age 85. The committee used these findings to calculate that 135 dominant or codominant oak saplings were needed at age 25 to produce 43 dominant or codominant oak trees at age 85 ($(43/0.32) \times 100 \approx 135$).

The committee used dominance probability studies conducted in Missouri and North Carolina to calculate how many oak seedlings per acre were needed at age 0 to produce 135 dominant or codominant oak saplings at age 25 (Loftis 1990b, Sander et al. 1984). Both studies followed the performance of oak reproduction for 5-8 years after the final harvest and then conservatively projected their likely crown positions at age 20. These projections, or dominance probabilities, reflected the influences of initial size of the oak reproduction and site quality (Table 2). Depending on these two factors, the committee calculated that 380-13,500 oak seedlings or sprouts per acre were needed at the time of the final harvest to produce 135 oak saplings at age 20. This range of oak seedlings and sprouts translated to 1-35 oak stems per 6-foot radius regeneration plot, depending on initial seedling size and site quality.

One factor lacking from the Missouri and North Carolina studies was the influence of excessive white-tail deer browsing of oak reproduction because herbivory was not a serious problem at either location. In Pennsylvania, deer browsing was a major obstacle to regenerating forests (Horsley et al. 2003; Marquis 1974, 1975; Marquis and Grisez 1978; Marquis and Brenneman 1981) and had to be considered in the seedling stocking criteria. For new oak, the committee decided that a minimum of 25 seedlings per plot was needed at deer impact levels 1 and 2 and 50, 100, and 200 seedlings per plot at deer impact levels 3, 4, and 5 (Table 1). Minimum seedling counts for established oak were half those of new oak; 12-100 stems per plot depending on the deer impact level. Competitive oak stocking was set at one stem per plot regardless of the deer impact level, because deer browsing damage is diminished for taller seedlings. However, competitive oak stocking did vary from 1-3 stems per plot by site quality, because mesophytic hardwood reproduction would become more problematic as site quality improved (Carvell and Tryon 1961, Crow 1988, Minckler and Woerheide 1965, Trimble 1973).

By 2000, harvested oaks were proven to produce highly competitive stump sprouts to varying degrees depending on the species and the diameter of the parent tree (Johnson et al. 2009). The probable contribution of oak stump sprouts to regeneration stocking was already in the pre-2000 versions of SILVAH (Marquis et al. 1992). Therefore, the committee opted to keep these probabilities as they were for deer impact levels 1 and 2 but decreased them by 50 percent for deer impact level 3 and discounted them completely for deer impact levels 4 and 5.

OAK REGENERATION PRESCRIPTIONS

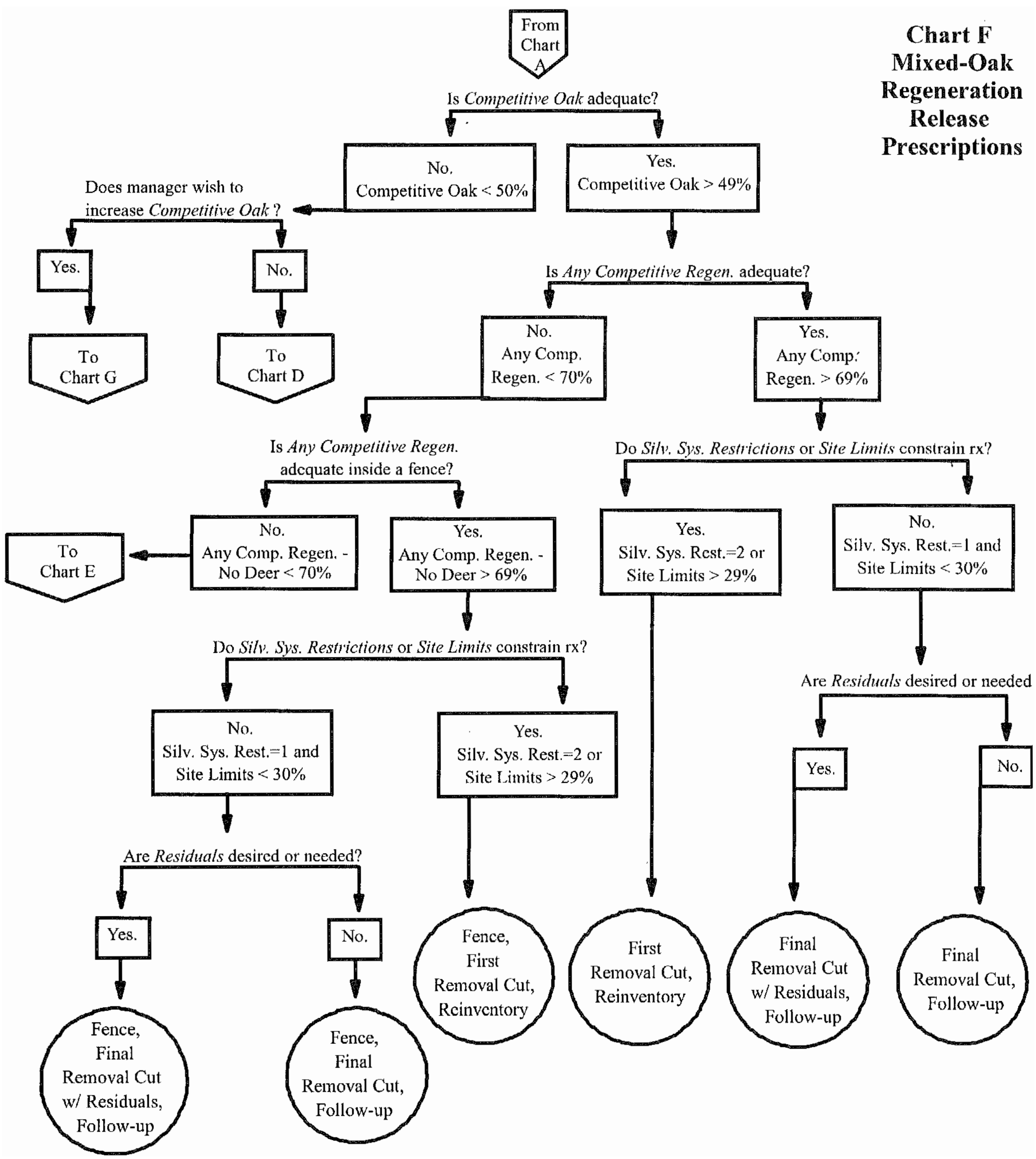
Once the committee had determined stocking criteria for oak reproduction, the next task was to review and revise the SILVAH prescriptions for their appropriateness in regenerating mixed-oak forests. At the time there were no oak-specific prescriptions; oak reproduction was treated the same as all other desirable seedlings. Because of this lack of differentiation between oak reproduction and that of other desirable species, pre-2000 SILVAH prescriptions tended to convert mixed-oak forests to Allegheny hardwood or other forest types. The committee members found this tendency to be unacceptable, so they began formulating new prescriptions designed around the silvics of oak and the oak regeneration process.

From the outset of this endeavor, the committee recognized that several intrinsic and extrinsic factors extended the longevity of the oak regeneration process, which could take 5-25 years. At the forefront of the intrinsic factors were the sporadic occurrence of acorn crops (masting) in the mid-Atlantic region and the root-centric growth pattern of oak seedlings (Brose 2011a, b). Masting of mature oaks tends to be periodic because of the physiological strain of producing large seeds. When there is an acorn crop, the resultant new seedlings emphasize root growth in lieu of stem development until the seedlings have a large enough root system to support sustained vigorous height growth (Brose 2011a). Both factors slow the oak regeneration process, and both can be adversely affected by numerous environmental factors (Loftis and McGee 1993). Consequently, an already slow regeneration process can be made even slower. For example:

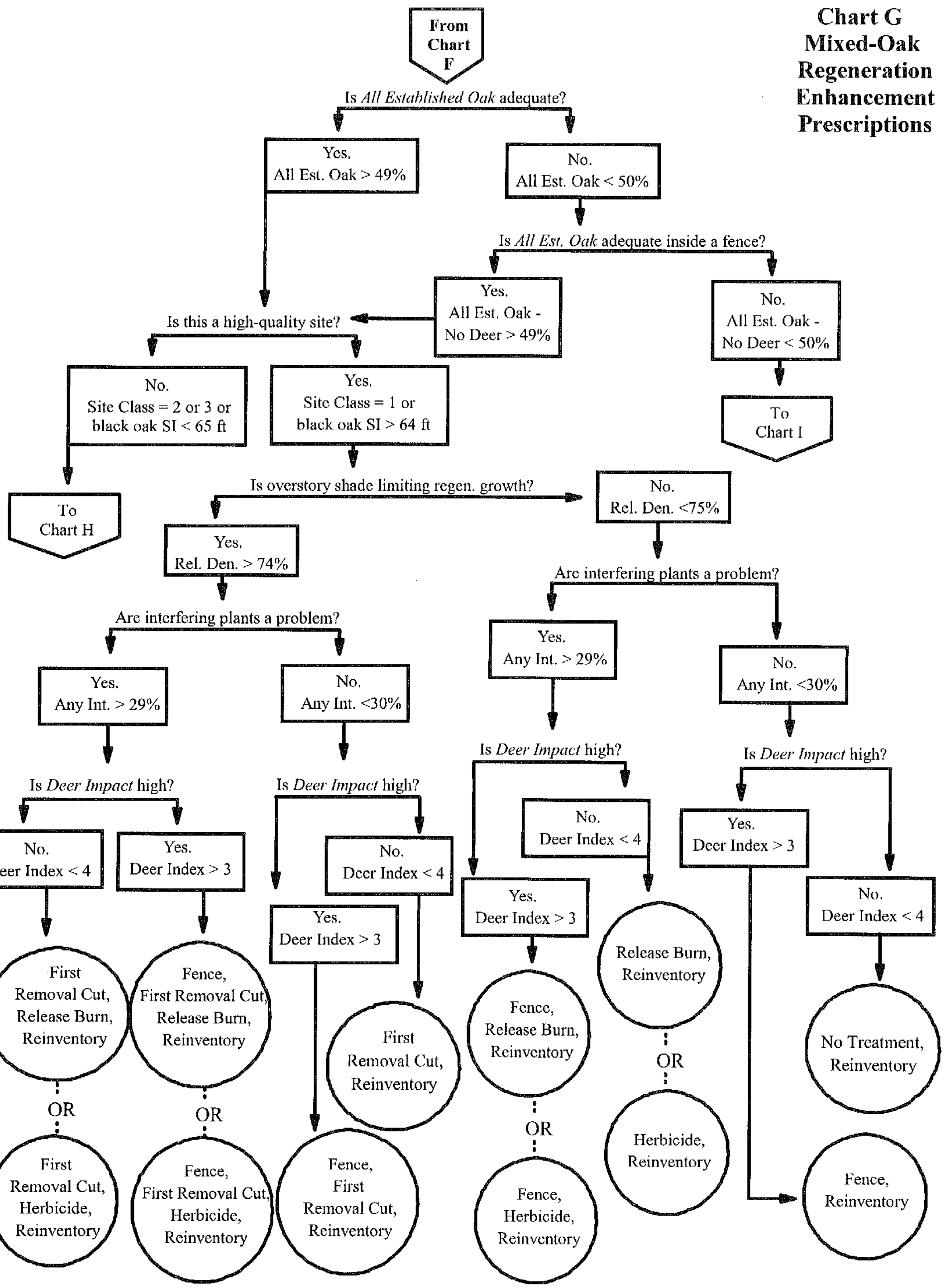
- Wet spring weather can result in poor pollination.
- A late frost can kill oak inflorescence.
- Summer droughts or defoliations can cause oaks to abort nascent acorn crops.
- Dense understory shade and deer browsing can prevent young oak seedlings from developing larger, more competitive root systems.

To account for the slow, punctuated nature of the oak regeneration process, the committee devised six decision charts (F to K) around common situations often found in the mid-Atlantic region (Fig. 1):

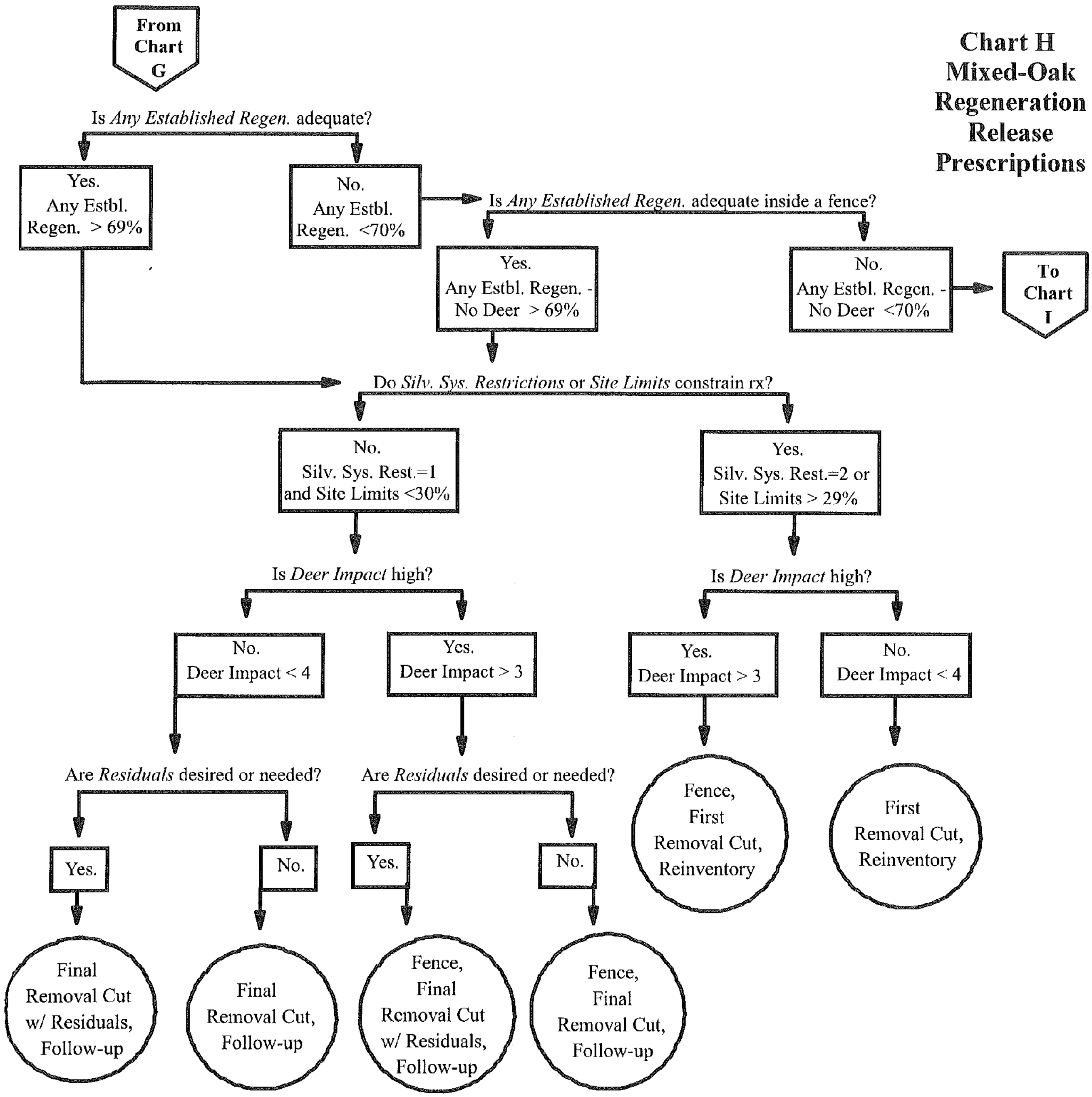
- Chart F: Competitive oak reproduction is adequate and ready for release. This chart is for oak stands nearing the end of the oak regeneration process. Such stands have an adequate stocking (≥50 percent) of competitive oak seedlings, ≥70 percent total competitive regeneration, and an overstory suitable for an economical final harvest. Of the six prescriptions, four were final removal cuts with deer fencing and retention of long-term residual trees as needed. The other two prescriptions were shelterwood first removal cuts, which were made for aesthetic or edaphic reasons.



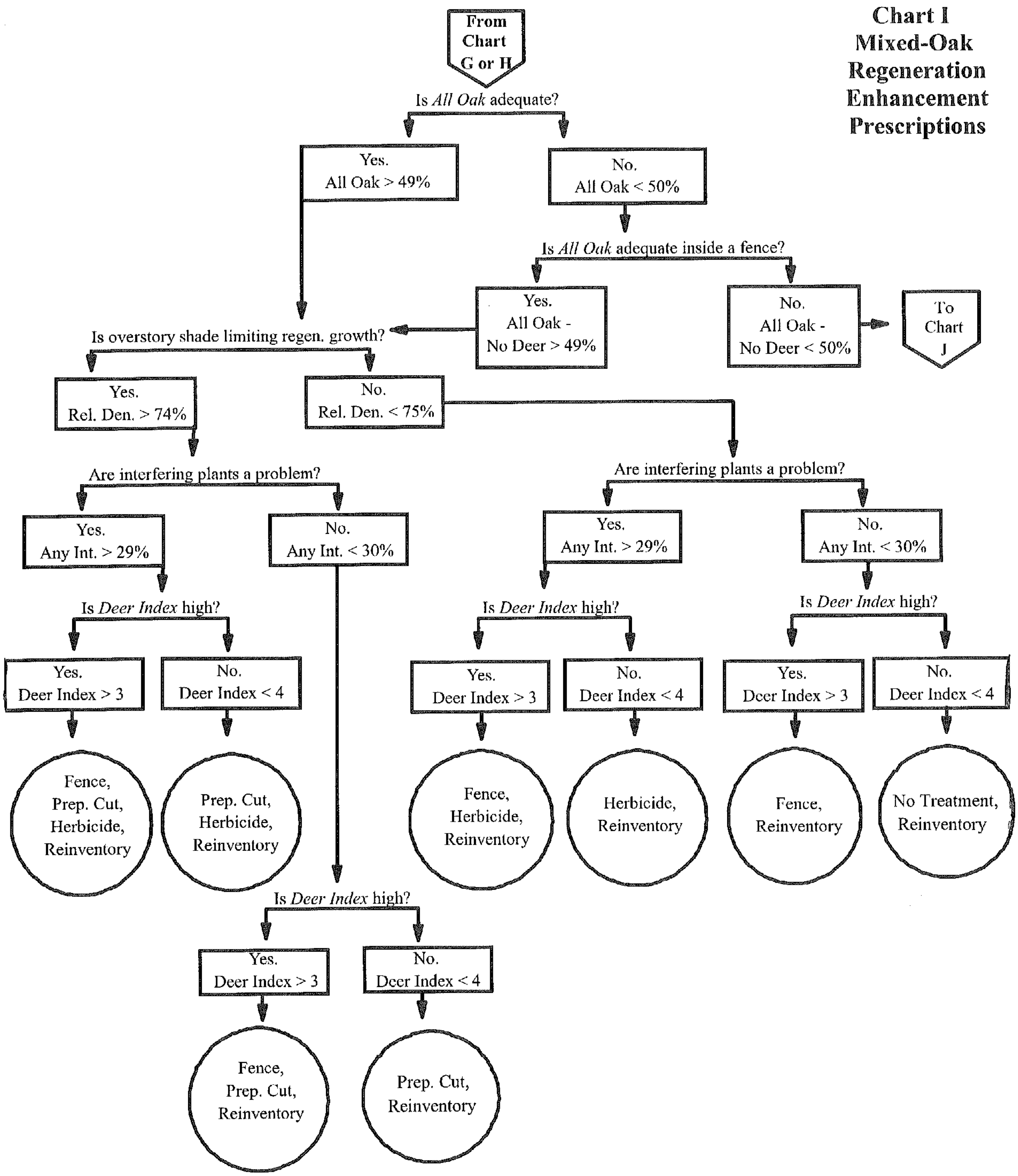
- Chart G: Established oak seedlings are adequate and ready for development into competitive reproduction. This chart addresses oak stands on high-quality sites (oak SI_{50} ≥70 feet) that are in the middle of the oak regeneration process and should be ready for a final harvest in 5 to 10 years if properly managed. These stands have at least 50 percent stocking of established oak seedlings, but these seedlings are not yet large enough for a final harvest due to fierce competition from other tree species. Also, one or more barriers (overstory shade, interfering vegetation, deer) hinder the development of those seedlings. A first removal cut of a two-cut shelterwood sequence is recommended to decrease shading, and either herbicide application or release burning is advised to combat interfering vegetation. Woven wire fencing is suggested to alleviate deer browsing. At the end of each prescription a reinventory is necessary to determine whether the stand is ready for the next sequence of treatments or Chart F.



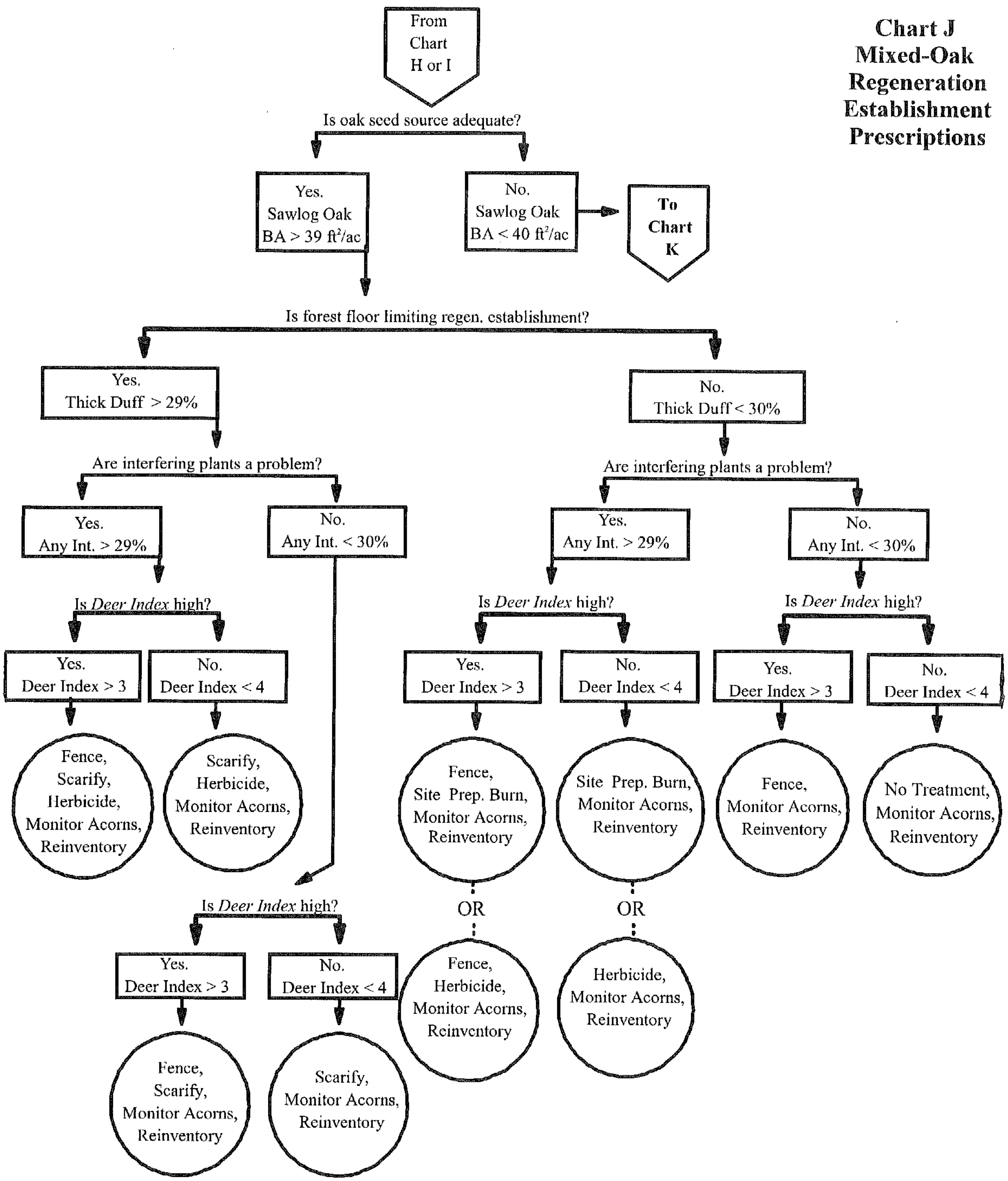
- Chart H: Established oak seedlings are adequate and ready for release. Chart H is for oak stands on low-quality sites (oak SI_{50} <65 feet) that have >50 percent stocking of established oak. Such stands are near the end of the oak regeneration process, because interfering vegetation is much less problematic; thus, small oak seedlings can be competitive (Johnson et al. 2009). Chart H prescriptions are nearly identical to those in Chart F, in that both recommend either final or first removal harvests. Deer fencing may also be recommended if post-harvest browsing is adversely affecting the oak reproduction.



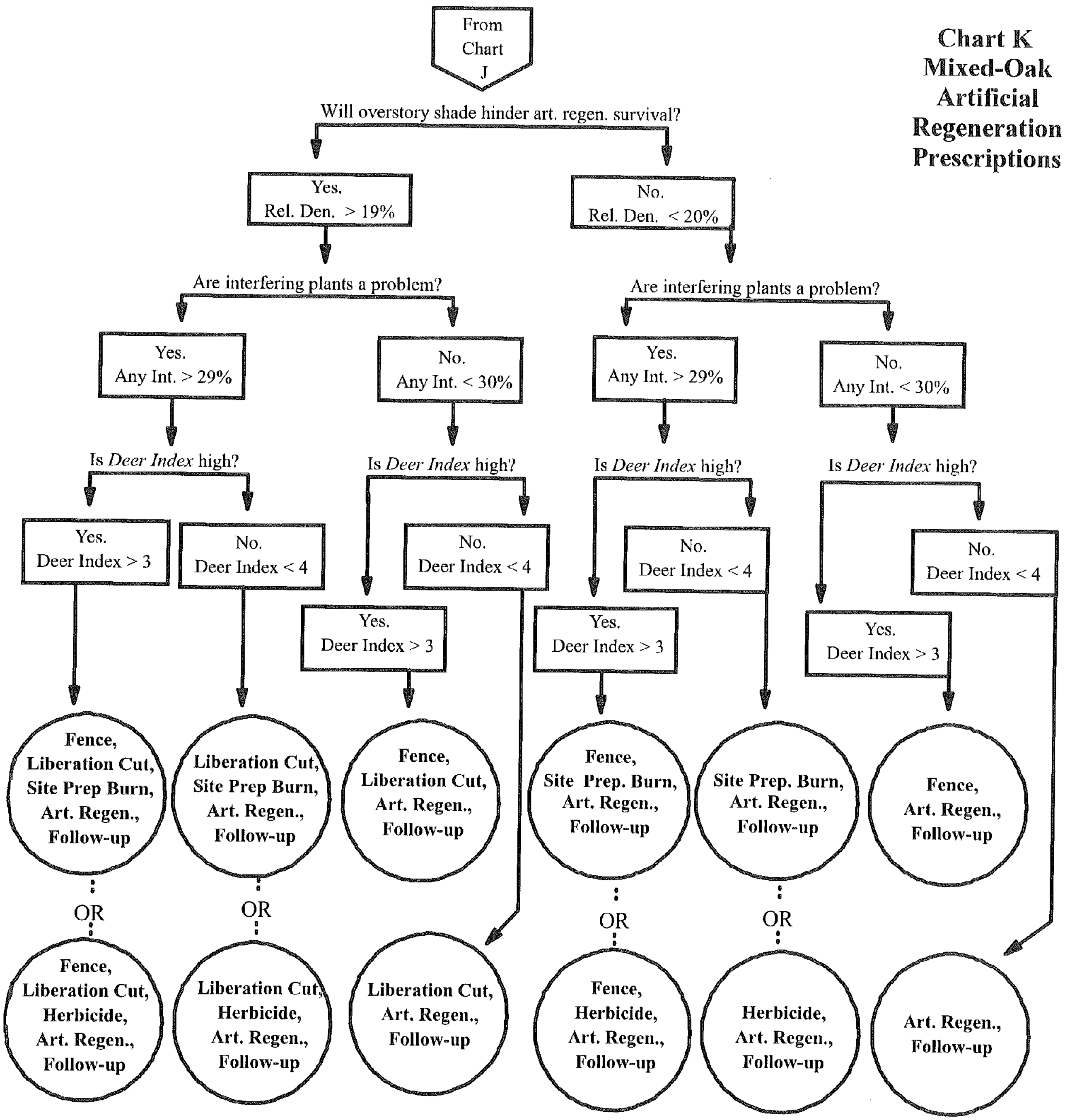
- Chart I: New oak seedlings are adequate and ready for development into established reproduction. Chart I addresses oak stands that recently had a good to bumper acorn crop resulting in the formation of a cohort of new oak seedlings that exceeds 50 percent stocking. Such stands are at the very beginning of the oak regeneration process and are many years from completion. The prescriptions are designed to foster the root development of the new oak seedlings while minimizing their mortality. This is done by gently increasing understory lighting via the preparatory cut of a three-cut shelterwood sequence and the use of individual stem herbicides. Fire is not a Chart I prescription, because the new oaks are too small to withstand burning (Miller et al. 2017). Fencing is advised if deer browsing is problematic and a subsequent inventory is necessary to determine when the stand is ready to proceed to Chart F, G, or H.



- Chart J: New oak seedlings are lacking, but an adequate seed source is present. This chart is for oak stands that do not have enough oak reproduction of any type (<50 percent cumulative stocking) to start the oak regeneration process. Such stands are between bumper acorn crops; the oak seedling cohort established after the last major masting event has died out and the next one is sometime in the future. These stands have an adequate acorn source (≥40-square-foot basal area of sawlog-size oaks) and may have interfering vegetation or root mat problems in the understory. The eight prescriptions include herbicide application, seedbed preparation burning, and soil scarification, which mitigate obstacles to establishing new oak seedlings coupled with monitoring for future acorn crops. A follow-up inventory is recommended to determine when these stands are ready to move onto the prescriptions of the preceding charts.



- Chart K: New oak seedlings and an adequate seed source are lacking. This chart is for oak stands that have been degraded by past disturbances such as insect defoliations, storm damage, or exploitative harvesting, which result in excessive removal of oak seed sources. These stands have lost enough of their overstory oaks to have insufficient seed source to establish new oak seedlings. The eight prescriptions recommend intensive site preparation treatments followed by relatively expensive artificial regeneration to compensate for the lack of seed source.



Within each of these possible starting points for practicing foresters, the committee developed 6 to 12 oak regeneration prescriptions. These prescriptions centered on even-age management, specifically the shelterwood system. Uneven-age silviculture was not considered; it had a long history of failure in the mid-Atlantic region because of chronic deer overpopulations and the chance it would devolve into diameter-limit cutting. This would result in undesirable changes in species composition. Generally, the oak regeneration prescriptions consisted of multiple treatments applied sequentially over several years. They included practices already used in the mid-Atlantic region; i.e., broadcast herbicide application and deer fencing, and ones successfully used in other regions such as midstory shade removal and prescribed burning (Brose et al. 1999, Loftis 1990a). The prescriptions also included subsequent inventories to ensure conditions were correct for the next treatment.

SCIENCE DELIVERY

Once the committee tentatively identified new oak stocking criteria and formulated draft prescriptions, they needed to be field tested and shared with practicing foresters. This dissemination served two purposes: it addressed the dearth of scientific management of mixed-oak forests in the region, and it facilitated partnered testing of the inventory criteria and prescriptions. The Forest Service scientists taught the new criteria for determining stocking of oak reproduction to approximately 100 PBF field foresters in early summer 2000. These foresters used the new criteria in their understory inventories for the next 16 months and then provided feedback to the committee on their applicability and ease of use. Generally, the foresters accepted the new criteria, but the committee made a few minor changes based on their recommendations. For example, established oak and competitive oak were combined for stands with an oak site index <70 feet at age 50 years.

Commencing in 2002, Forest Service scientists disseminated the interim inventory guidelines and the draft prescriptions via annual training sessions held at Clear Creek State Forest near Brookville, PA. Additional workshops were provided in Kentucky, Maryland, Ohio, and West Virginia, where participants provided feedback based on local experiences. To date, more than 800 of these forest managers have attended the training sessions held at Clear Creek State Forest or one of the periodic sessions held in neighboring states. The oak training session is mandatory for all new foresters hired by the PBF as well as the Pennsylvania Game Commission and the Allegheny National Forest.

By 2007, revisions to the inventory criteria and prescriptions based on feedback from the PBF foresters had largely ceased. Therefore, the Forest Service scientists published a SILVAH–oak regeneration guidebook (Brose et al. 2008). Since this guidebook was published, more than 2000 copies of the have been distributed to forest managers throughout the eastern United States.

SUBSEQUENT RESEARCH

Expanding SILVAH to mixed-oak forests highlighted several knowledge gaps in regional oak ecology and silviculture. The principal scientists of the SILVAH–oak endeavor have been able to address many of these gaps thanks to continued financial support by the PBF and funding from other sources, such as the Forest Service and the Joint Fire Science Program. Research studies that have been conducted or are ongoing include:

1. The Acorn Study. This project followed the survival of the 2001 bumper acorn crop and subsequent oak seedling cohort for 8 years (Brose 2011b). Principal findings were:
    a. Soil scarification is valuable in protecting acorns from insects, diseases, weather, and wildlife consumption.

b. Deer browsing and dense understory shade were reaffirmed as the two most detrimental obstacles to oak seedlings.

2. The Dominance Probability Study. This large-scale, long-term project documents the post-harvest performance of oak seedlings and sprouts across a wide variety of oak site indices throughout Pennsylvania (Brose et al. in press). Currently in its 15th year, it will produce oak dominance probabilities that will replace the interim ones derived from the Missouri and North Carolina studies.
3. The Limiting Factors Study. Another long-term study that follows the survival and growth of oak seedlings from the 2001 acorn crop (Miller et al. 2017). A major finding was that multi-treatment prescriptions are needed to control interfering ferns and competing non-oak reproduction, deer browsing, and understory shade.
4. The Mountain Laurel Study. This project identified the level of cover at which mountain laurel starts interfering with oak seedlings and the strengths and weaknesses of several possible control strategies (Brose 2016, 2017). It also spawned a follow-up study to identify potential broadcast herbicide prescriptions (Brose and Miller 2019, Miller et al. 2016).
5. The Oak Rooting Study. This project examined the development of the roots of oak seedlings growing in the understory light conditions created by a three-cut shelterwood prescription (Brose 2011a, Brose and Rebbeck 2017). Key findings were:
   a. Northern red oak can develop roots in preparatory-cut stands.
   b. First removal cuts must create and maintain at least 30 percent sunlight for all oak species.
   c. Root development must continue for at least 6 years before oak seedlings switch to emphasize height growth.
6. The Prep Cut Study. This project focused on the survival and development of northern red oak seedlings subjected to three levels of understory lighting, all of which could be achieved via a shelterwood prep cut treatment (Miller et al. 2014). A major finding was that removing non-oaks <3-inch diameter at breast height was optimal; removing fewer did little to promote oak seedling survival and growth, and removing more sparked competition from black birch.
7. SILVAH Success Study. This ongoing project tests the SILVAH-generated prescriptions applied by PBF foresters in the early to mid-2000s (Rittenhouse et al. 2018).

CONCLUSIONS

Expanding SILVAH to be more applicable to the mixed-oak forests of the mid-Atlantic region has been a 17-year journey of collaboration and cooperation between Forest Service scientists and a broad array of other forestry professionals. By using relevant oak research from other states, the committee could quickly produce tentative guidelines for inventorying oak seedlings and determining stocking criteria to formulate draft prescriptions. Field testing and feedback from numerous foresters have helped hone those criteria, guidelines, and prescriptions to the environmental conditions of Pennsylvania's forests and has sped acceptance as the practitioners have developed a sense of ownership in the developmental process. Moreover, practicing foresters have begun to see positive results in regenerating oak forests from their own application of SILVAH. These cooperative relationships will endure, thereby keeping SILVAH current and useful to future managers of mixed-oak forests in the mid-Atlantic region.

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OAK SILVAH IN OHIO AT THE LANDSCAPE SCALE

Matthew P. Peters and Joanne Rebbeck[1]

Insights for Managers

- **State and federal land management agencies are using this approach to establish short- and long-term priorities for even-age management treatments of oak-hickory stands.**
- **The Ohio Interagency Forestry Team is applying the model across the 17-county project area to align agency programs of work with family forest landowner interest in managing oak across the region.**
- **Managers can use these tools to assess public and private land opportunities to prioritize investments in oak management in southeastern Ohio by estimating the cost of oak treatment based on site productivity and oak regeneration.**
- **Managers and scientists can apply this modeling approach to other species of interest such as the nonnative invasive tree, Ailanthus.**

INTRODUCTION TO OHIO FORESTS

Forests cover 8.2 million acres in Ohio, encompassing 31 percent of the state's land area (Widmann 2014). Eighty-three percent is privately owned; 17 percent is publicly owned. Most forest land is in the unglaciated southeastern area of Ohio and is dominated by oak-hickory forests (Fig. 1). These provide critical habitat for more than 100 wildlife species, which include at-risk animals such as wood thrush (*Hylocichla mustelina*), cerulean warbler (*Setophaga cerulea*), and timber rattlesnake (*Crotalus horridus*). The topography of these landscapes is highly dissected and creates spatially heterogeneous microenvironments that influence oak-hickory advance regeneration stocking (Iverson et al. 2017). Mature mixed-oak forests grow on a variety of aspects and slope positions with site indices of 55-80. These overstories are dominated by white oak (*Quercus alba*), chestnut oak (*Q. prinus*), and black oak (*Q. velutina*). Midstory and sapling layers are dominated by red maples (*Acer rubrum*) and sugar maples (*A. saccharum*); however, numerous species including blackgum (*Nyssa sylvatica*), yellow-poplar (*Liriodendron tulipifera*), beech (*Fagus grandifolia*), and sourwood (*Oxydendrum arboreum*) are present. Deer pressure is generally lower in Ohio than in Pennsylvania and other eastern U.S. states. Nonnative plant species such as Ailanthus (*Ailanthus altissima*), autumn olive (*Elaeagnus umbellata*), multiflora rose (*Rosa multiflora*), twinberry honeysuckle (*Lonicera involucrata*), and stiltgrass (*Microstegium vimineum*) are problematic and continue to expand within these forests.

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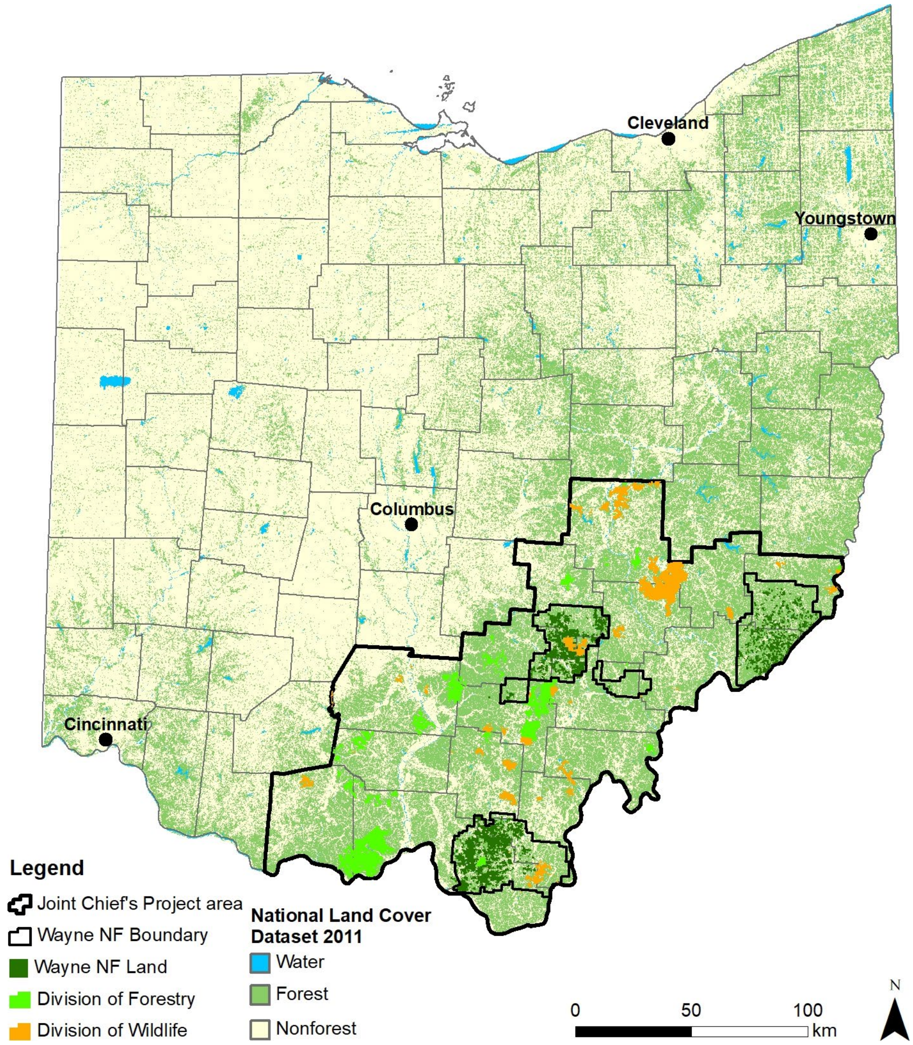

Figure 1.—Regional map of USDA Joint Chiefs' Landscape Restoration Partnership Project, Collaborative Oak Landscape Management in Ohio's Appalachian Mountains project area, including boundaries of WNF and Ohio Divisions of Forestry and Wildlife lands. Land cover data indicate the distribution of forested land in Ohio.

As in other parts of the eastern United States, removal of high-quality white oak from Ohio forests is exceeding recruitment. From 1991 through 2011 select white oak sawlog recruitment equaled removal, and pole-sized recruitment declined 11.8 percent, from 32.6 to 20.8 million trees (Widmann 2014). Management to sustain Ohio's mixed-oak forest to support wildlife habitat and timber production is a priority for the region. The recent boom in bourbon production increases the need for high-quality white oak stave logs, which production facilities are stockpiling. Speyside Bourbon Cooperage in Jackson, OH, began production in May 2016. It produces 1500 barrels and consumes 53,000 board feet of quarter-sawn white oak staves each day.[2] The Amish-based furniture manufacturing cluster in Holmes and surrounding counties in northeastern Ohio is a growing sector of the domestic furniture industry, which also uses Ohio's oak resource (Bumgardner et al. 2011).

[2] A. Ramirez, production manager, Speyside Bourbon Cooperage, 960 E. Main St., Jackson, OH 45640. Personal communication, October 13, 2017.

BRINGING OAK SILVAH TO OHIO

The first Oak SILVAH training session in Ohio was held in 2009. To date, more than 110 alumni represent a mix of private, county, state, and federal land management agencies, private consulting foresters, service foresters, and academics. The 4-day training sessions, typically held biannually at the Vinton Furnace State Experimental Forest (https://www.nrs.fs.fed.us/ef/locations/oh/vinton-furnace/) in Vinton County, Ohio, have become so popular that wait lists develop several months before an event.

Shortly after the first Ohio SILVAH training session, the Ohio Department of Natural Resources Division of Forestry (ODOF) piloted SILVAH (2010-11), which coincided with certification through the Forest Stewardship Council and the Sustainable Forestry Initiative. The SILVAH decision support system complemented the sustainable certification principles and standards for timber management of the Forest Stewardship Council and Sustainable Forestry Initiative. In 2015, Ohio Division of Wildlife (ODOW) partnered with the National Wild Turkey Federation by contracting SILVAH inventories in 13 wildlife management areas (42,526 acres), which were stratified by forest type, slope position, and tree height classes. Managers and technical staff from ODOW and ODOF attend biennial Oak SILVAH training sessions in Ohio and use SILVAH for forest inventories and management activities across Ohio.

The SILVAH system is addressing the forest management needs of Ohio's public and private landowners, and its use by private consulting foresters in Ohio continues to increase. The USDA Joint Chiefs' Landscape Restoration Partnership Project, Collaborative Oak Landscape Management in Ohio's Appalachian Mountains, incorporated Oak SILVAH training as a cornerstone for staff development. It includes the Wayne National Forest (WNF), Natural Resource Conservation Service (NRCS), Ohio Division of Soil and Water Conservation Districts, and ODOF service foresters.

JOINT CHIEFS' LANDSCAPE RESTORATION PARTNERSHIP PROJECT, COLLABORATIVE OAK LANDSCAPE MANAGEMENT IN OHIO'S APPALACHIAN MOUNTAINS

The USDA Forest Service and NRCS received Joint Chiefs' Landscape Restoration Partnership Project funding from 2015 through 2017 to work with state agencies such as ODOF and nongovernmental organizations with a goal to coordinate inventorying, management, and monitoring of oak-hickory forests in a 17-county area of southeastern Ohio (Figure 1) to improve the efficiency and effectiveness of landscape-scale management. The main goal is to identify and prioritize areas of investment to maintain or restore oak-hickory. The agencies developed data-sharing technologies, created a regional SILVAH inventory database, and modeled ecological landtypes (LTs) that favor oak habitat to achieve this goal and create an effective multiagency partnership. A major outcome has been the formation of a chartered working group, the Ohio Interagency Forestry Team, which operates under a new business model:

- A team charter outlines processes and expectations.
- A regional science framework includes data, tools, and training.
- Landscape-scale conservation strategies enhance government services and programs.

Data Sharing

Data-sharing technologies archive and provide access to datasets that are relevant to the project objectives that may otherwise be difficult to distribute among collaborators. Examples include Data Basin (https://databasin.org/) and Esri's ArcGIS Online (https://www.esri.com/en-us/arcgis/products/arcgis-online/overview), both of which allow geospatial data to be shared and mapped on a website that allows users to visually analyze data. Some data-sharing technologies can incorporate data provided as a map service, digital dynamic map layers, to reduce maintenance requirements by updating shared files in real time as hosting agencies edit and manage records. An interactive map viewer is also integrated with some basic tools for analyzing data. It enables users who might not use a full suite of geographic information system (GIS) functions to visualize, query, and extract pertinent records. Information sharing will support coordinated treatments and the development of landscape-scale strategies.

SILVAH Regional Database

The regional SILVAH database incorporates more than 5 years of data records collected by ODOF and ODOW, WNF, and Forest Service Forest Inventory and Analysis (FIA). FIA inventories are not collected using the SILVAH protocol and required some additional processing to derive information related to the status of oak in the overstory and understory layers. The FIA records do, however, provide representation of the species compositions that private forest landowners might be managing. FIA sampling protocols were revised in 2012 to collect SILVAH regeneration information in 24 northeastern states. This fills an information gap for smaller size classes of hardwood (12 inches tall) and conifer (6 inches tall) seedlings up to saplings (1 inch diameter at breast height [d.b.h.]). Data from Forest Service National Forest Common Stand Exams, as well as other formats such as T-Cruise, can also be pulled into the SILVAH software and analyzed; however, because SILVAH operates at the stand level and does not have a spatial component, locations of individual inventory plots are unknown. The additional refined spatial information would be useful, but access to other inventory formats can increase the ability of the database to provide current forest composition and structure information.

We calculated a metric of "oakiness" for each SILVAH and FIA inventory plot in the 17-county region. This represents the percentage of oak species in the overstory canopy by basal area and a weighted oak index that indicates the stocking of oaks in the understory layer. We used the following definitions: (1) competitive, >3 feet in height or ¾-inch root collar diameter; (2) established, 1-3 feet in height or ¼- to ¾-inch root collar diameter; and (3) new, <1 foot in height (Brose et al. 2008). We then weighted and summed counts of oak species within each class by 25, 12, and 1, respectively. Oak index values >24 can be considered stocked with advanced oak regeneration when deer browsing pressures are low.

Modeling Ecological Landtypes

Maintaining or restoring oak-hickory in these forests requires knowing the locations where these species would have suitable habitat. We used the research of Hix and Pearcy (1997) and Pearcy et al. (1999) to model six ecological landtype phases (LTPs) across 17 southeastern Ohio counties derived from 33-foot elevation and terrain variables. We then aggregated these LTPs, which define ridgetops, northeastern and southwestern upper and lower hillslopes, and valley bottomlands, into three LTs that represent favorable habitat for oak-hickory forests. We evaluated LTs and LTPs across this region by examining corresponding SILVAH inventory records: (1) where oak was not present at the site; (2) present in either the overstory or understory; or (3) present in both the overstory and understory canopies.

APPLYING LANDTYPE MODEL OUTPUTS AND SILVAH TO PRIORITIZE MANAGEMENT INVESTMENTS

Based on the modeled ecological LTs, the 17-county region (5,425,198 acres) comprises 39.7 percent dry oak forest, 29.3 percent dry-mesic mixed-oak hardwood forest, and 31.1 percent rolling bottomland mixed-hardwood forest (Iverson et al. 2018). Oak and hickory species have the potential for favorable habitats within the dry oak and portions of the dry-mesic mixed-oak hardwood forests, indicating that at least one-third of the region is unfavorable for oak-hickory forests. However, even though two-thirds of this region can likely support oak-hickory forests, past land-use and management practices may hinder the natural establishment and recruitment of oak into the canopy (Brose et al. 2008, Iverson et al. 2017). SILVAH inventories and recommended silvicultural prescriptions would inform forest managers of current conditions and the possible actions to reach an intended goal or condition.

Development of a Geographic Information Systems Tool

We developed a GIS tool that computes areal summary statistics of ecological LTs or LTPs and identifies any corresponding SILVAH inventories and land cover data within one or more areas of interest (e.g., stand or property) to help forest managers assess the investment of either maintaining or restoring oak-hickory to the landscape. Forest stands can vary in size and shape, species composition, and land-use history, and contain multiple morphological landscape components. This tool's main feature, therefore, is to help compare information that represents current or potential conditions of species composition and begin the process of determining which silvicultural practices may be required to maintain or restore oak-hickory stands. Identifying these "investment zones" can help to prioritize and align management practices with a broader objective for private and public landowners.

Forest Management Examples

1. Wayne National Forest

The WNF used information from the 17-county SILVAH database and modeled ecological LTs (Fig. 2) to identify stands where oak-hickory restoration could create early successional habitat to benefit wildlife in the short term while working toward the long-term goal of maintaining or restoring oak-hickory forest. Knowing how much of the WNF has been modeled as favorable habitat for oak-hickory forest, and the potential status of oak-hickory stands on neighboring landscapes, can help develop scenarios of management objectives that could aid in long-term decisionmaking.

2. Ohio Division of Wildlife

SILVAH has become an integral part of ODOW's tactical plan to manage wildlife habitat to sustain viable populations of native forest wildlife species that require large forested landscapes. After completing georeferenced forest stand mapping in 2014, ODOW partnered with the National Wild Turkey Federation to contract a SILVAH forest inventory of 13 state wildlife areas (approximately 43,000 acres) in eastern Ohio. The forest inventory employed a stratified design in forest stands with two forest types (mesic hardwood and xeric hardwood/mixed hardwood-pine), three slope positions (low, mid, and high) and two tree height classes (60-80 feet tall and >80 feet tall, based on LiDAR). Georeferenced overstory and understory SILVAH plot data are stored in an Esri ArcGIS geodatabase. These data are being used to support the development of long-range wildlife area management plans, to use SILVAH's decision support software to identify appropriate silvicultural prescriptions, and to support forest wildlife habitat management planning and wildlife habitat suitability index modeling.

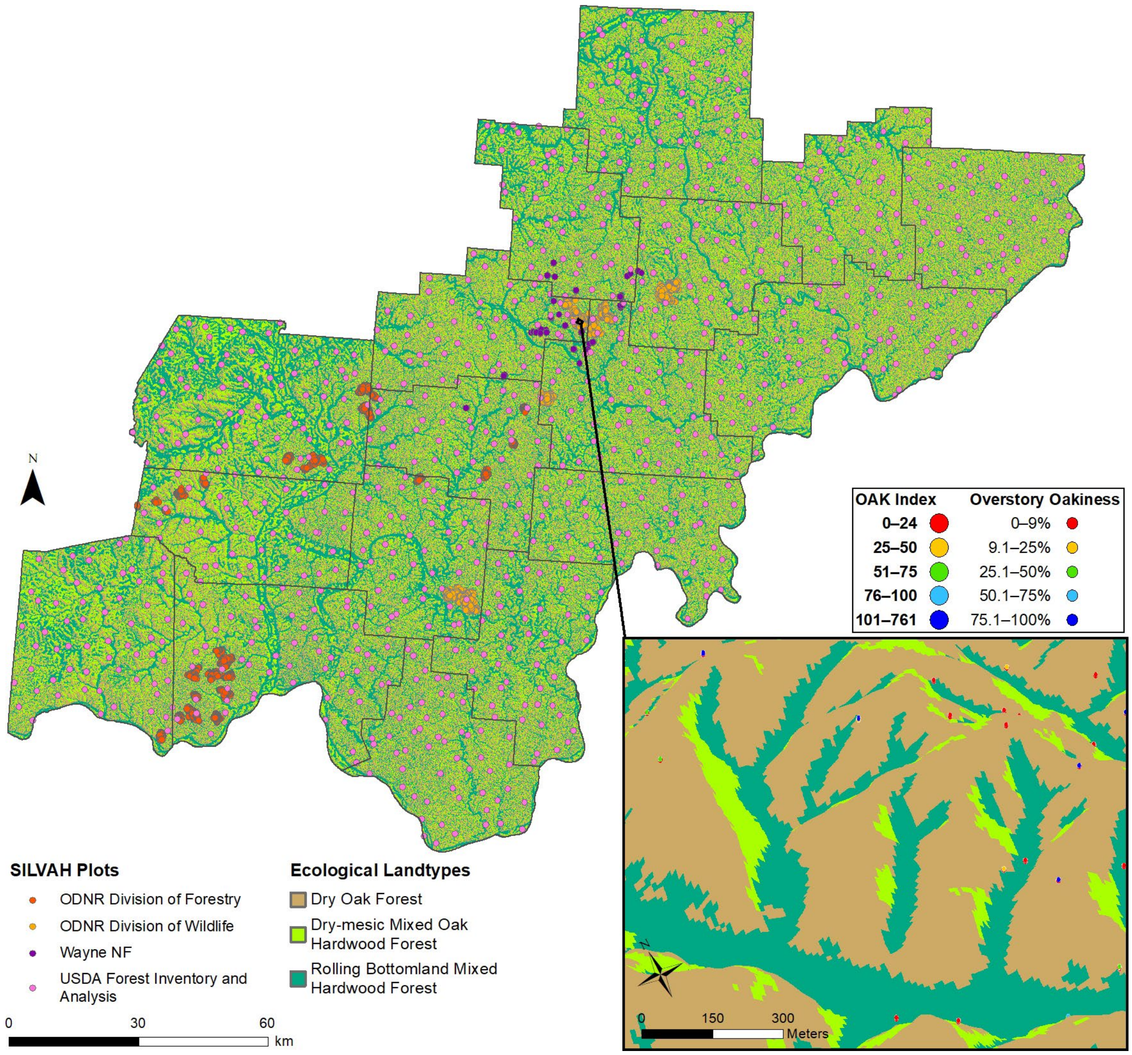

Figure 2.—Distribution of SILVAH inventory plots and modeled ecological landtypes (LTs) within the Joint Chiefs' project area in southeastern Ohio. Inset of 3-dimensional terrain with LTs and overstory percent "oakiness" and understory oak index values from SILVAH plots. Oak Index values >24 can be considered stocked for oak advanced regeneration when deer browsing is low.

CONCLUSION

In the 8 years since the first Ohio Oak SILVAH training session was first held, the Ohio forestry community has embraced the SILVAH Community of Practice. Input from its members led to the incorporation of a nonnative invasive plants module into the SILVAH software. Private consulting foresters eagerly serve as beta testers for software updates and provide constructive feedback. Wait lists months in advance of training sessions are now the norm. The WNF, NRCS OH, and the ODOF and ODOW have conducted numerous SILVAH inventories and contributed these to a regional database that is now being combined with new FIA understory data to extend SILVAH science to the landscape scale (Fig. 3). These same public agency managers have increased their effectiveness in collaborating to sustain oak forests and wildlife habitats across large landscapes and ownership boundaries. The Ohio Interagency Forestry Team is using the ecological LTs to align agency programs of work with family forest landowner interests in managing for oak across the 17-county Joint Chiefs' Landscape Restoration Partnership Project, Collaborative Oak Landscape Management area. The SILVAH community of practice has taken root in Ohio, and collaboration among diverse partners continues to strengthen.

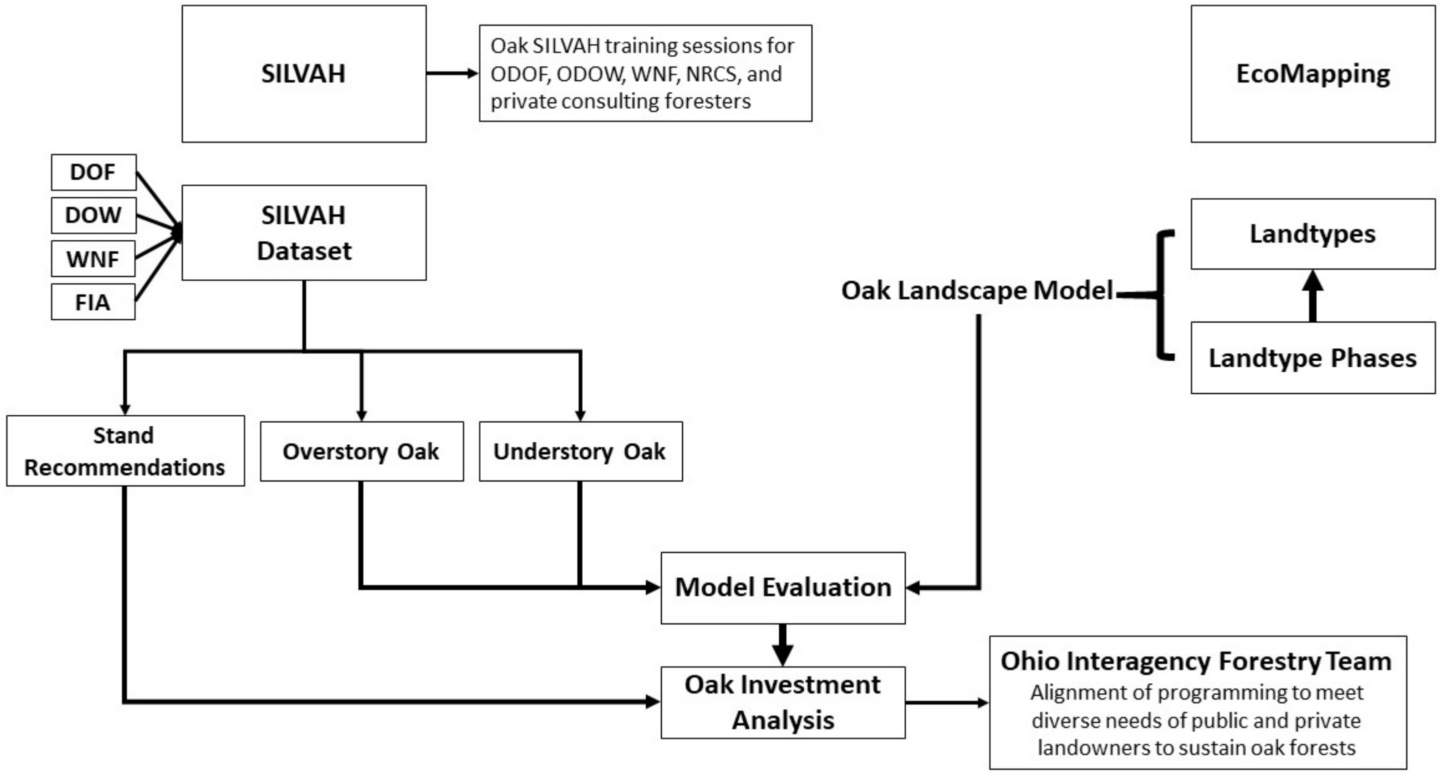

Figure 3.—Linkages of SILVAH to the oak landscape model, oak investment analysis, and incorporation into the business model for the Ohio Interagency Forestry Team.

ACKNOWLEDGMENTS

The modeling work presented here would not have been completed without the contributions of Louis Iverson, landscape ecologist, Northern Research Station in Delaware, Ohio, and Jarel Bartig, Ohio interagency liaison and forest silviculturist/landscape ecologist, WNF. We are indebted to Carlen Emanuel, former private landowner liaison for The Nature Conservancy Ohio for the assistance in bringing Oak SILVAH training to Ohio and incorporating the nonnative invasive plant module into the SILVAH software.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

SUGAR MAPLE DECLINE AND LESSONS LEARNED ABOUT ALLEGHENY PLATEAU SOILS AND LANDSCAPES

Robert P. Long, Stephen B. Horsley, Scott W. Bailey, Richard A. Hallett, and Thomas J. Hall [1]

Insights for Managers

- **A long-term forest liming study showed the critical importance of base cations for sustaining sugar maple crown health, growth, and survival.**
- **A topographic gradient study examined the distribution of base cations on the landscape in relation to sugar maple health and found that unglaciated summits, shoulders, and upper backslopes had the most crown dieback and mortality.**
- **Foliar calcium and magnesium were lowest on the unglaciated upper landscape stands and, combined with two or more moderate to severe defoliations in the preceding 10 years, cause extensive sugar maple dieback and mortality.**
- **Bedrock parent material and hydrologic flow paths were important factors that affected where sugar maple declined on unglaciated sites.**
- **A 30-year retrospective study that used archived soils from four forested and undisturbed sites originally sampled in 1967 showed that changes in soil base cation status and acidity over 30 years was a predisposing stressor for sugar maple.**
- **This multidisciplinary research produced a new understanding of the factors that led to the widespread sugar maple decline episode.**

INTRODUCTION

Sugar maple (*Acer saccharum* Marsh.) decline was a major forest health challenge in northern Pennsylvania starting in the mid- to late 1980s and continued through the mid-1990s. During this time sugar maple suffered extensive crown dieback and rapid mortality, primarily on the unglaciated Allegheny Plateau in northwestern and north-central Pennsylvania (Drohan et al. 2002, Horsley et al. 2000). Declining trees exhibited a slow loss of vigor and increased fine twig dieback, which was followed by large branch mortality. This frequently ended in tree death (Kolb and McCormick 1993). Surveys conducted as part of the North American Maple Project found sugar maple healthy in most parts of its range, though declines in Quebec were noted in the mid- and late 1980s (Allen et al. 1992, 1995, 1999). In northern Pennsylvania a series of stressors, which included insect defoliators and extreme drought, played a significant role in accelerating crown dieback and mortality.

Historically, sugar maple declines have not been limited to northern Pennsylvania; other declines have been reported in parts of New England, the Lake States, and Quebec and Ontario (Bal et al. 2015). A common theme in these declines is the interaction with nutrient

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stress. Across these regions, nutrients implicated with sugar maple dieback included nitrogen (N), calcium (Ca), magnesium (Mg), phosphorus (P), and potassium (K) (Bal et al. 2015). Additionally, soil acidification caused the potentially toxic cations aluminum (Al) and manganese (Mn) to become more readily available in soils, which created an additional stressor that affected sugar maple health and growth (Bal et al. 2015, Halman et al. 2013). Several studies also showed sugar maple growth to be related to soil base cation supplies; sugar maple growth decreased on sites with poor base cation status (Bishop et al. 2015, Duchesne et al. 2002, Long et al. 2009).

Our research began in 1993 and continued into the 2000s. Portions of our work covered a broad geographic range of sugar maple sites in the northeastern United States from northern Pennsylvania to New York, Vermont, and New Hampshire (Hallett et al. 2006). Three major related research projects and their results will be described here:

- Long-term forest liming impacts on northern hardwoods
- Sugar maple health and growth along topographic gradients
- Long-term changes in forest soil chemistry

In combination, these research efforts led to conclusive findings regarding the principal factors for sugar maple decline and mortality in Pennsylvania. Recommendations and management tools were developed to help foresters and land managers select sites where sugar maple could be sustained even if severe stressors such as drought and defoliation occurred.

RESEARCH PROJECTS

Forest Liming Impacts on Northern Hardwoods

The lime study was initiated in 1985 in cooperation with the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry, to determine whether deer or acidic deposition, or both, were responsible for difficulty in regenerating more diverse species (primarily red and sugar maples) in north-central Pennsylvania (Auchmoody 1985). Dolomitic lime was applied in fall 1985, at a high rate (22.4 mg ha^{-1}), to reduce potential Al toxicity associated with acidic deposition and promote diverse seedling regeneration in fenced and unfenced plots at four unglaciated locations (Long et al. 1997). An herbicide treatment was also overlaid on the lime treatment to control interfering plants, but this treatment had no effect on overstory responses and is not considered here (Long et al. 1997). Stands at all four replications were thinned to 50 percent relative density in the winter of 1985–86 to provide sufficient light for regeneration. Sugar maple seedling regeneration was only temporarily improved by liming but was ultimately unaffected by lime application or fencing (Long et al. 1997). Concurrent with the initiation of this study was the widespread crown dieback and mortality of sugar maple in the unglaciated parts of northern Pennsylvania (Horsley et al. 2000). This event shifted the focus of the study to the overstory community (Long et al. 1997), which was composed of sugar maple, American beech (*Fagus grandifolia* Ehrh.), and black cherry (*Prunus serotina* Ehrh).

By 1992 the only notable results were significant increases in exchangeable Ca and Mg and decreases in acidity, Al, and Mn in the upper 15 cm of mineral soil (Fig. 1) (Long et al. 2015). By 1995 it was evident that sugar maple growth and crown vigor were sustained in limed plots compared with trees in unlimed plots. In cooperation with the Pennsylvania Bureau of Forestry, overstory diameter growth and crown health, along with soil and foliar nutrients, were intensively monitored through 2008 (Long et al. 2015).

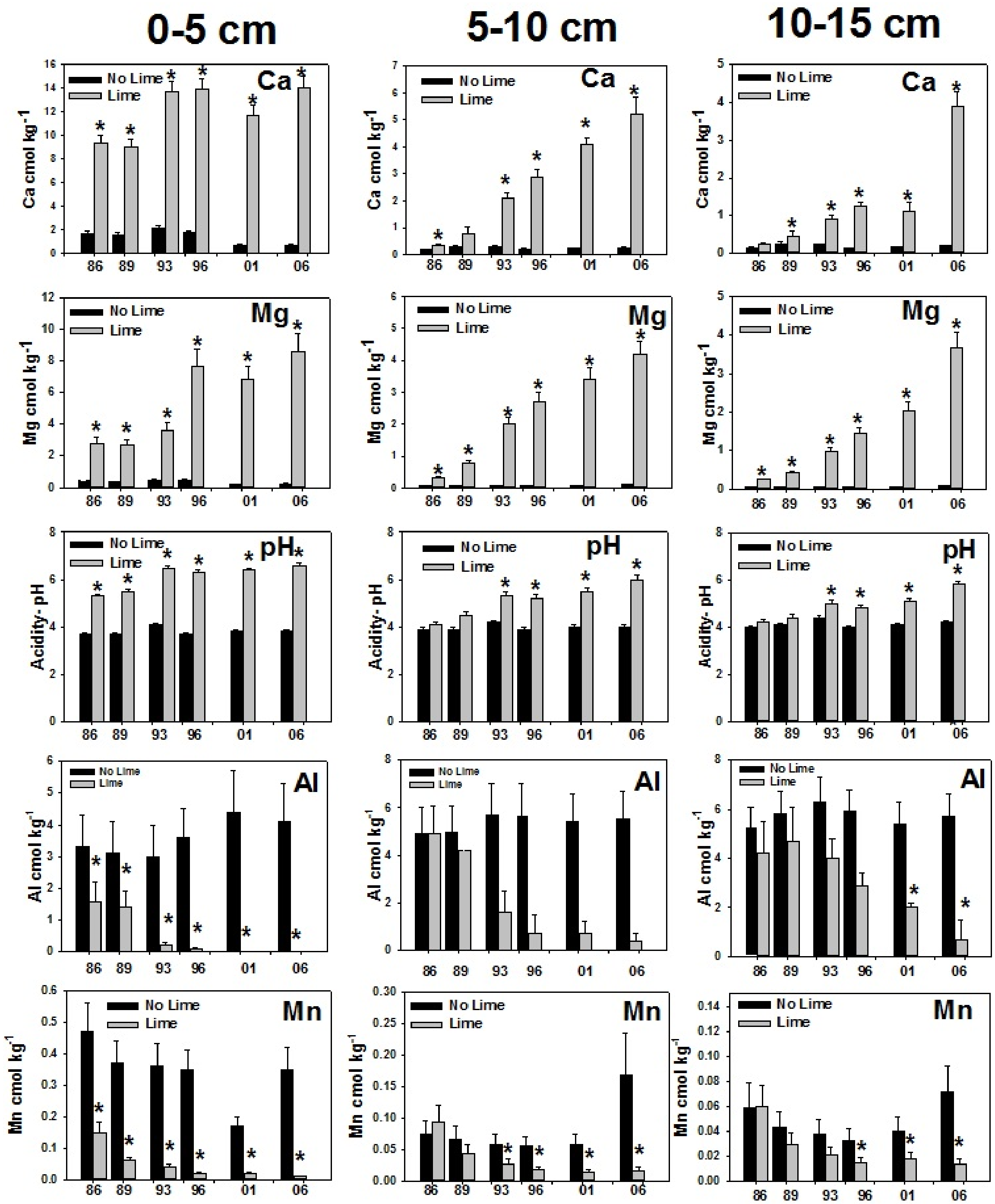

Figure 1.—Least square means from repeated measures analysis of lime treatment effects on soil-exchangeable Ca, Mg, Mn, Al, and pH in 1986, 1989, 1993, 1996, 2001, and 2006. Separate analyses were conducted for depths of 0–5, 5–10, and 10–15 cm. All elements and pH had significant ($\alpha \leq 0.05$) lime × year interactions and Tukey-Kramer pairwise comparisons. Significant differences between lime and no lime treatments are noted by an asterisk (*).

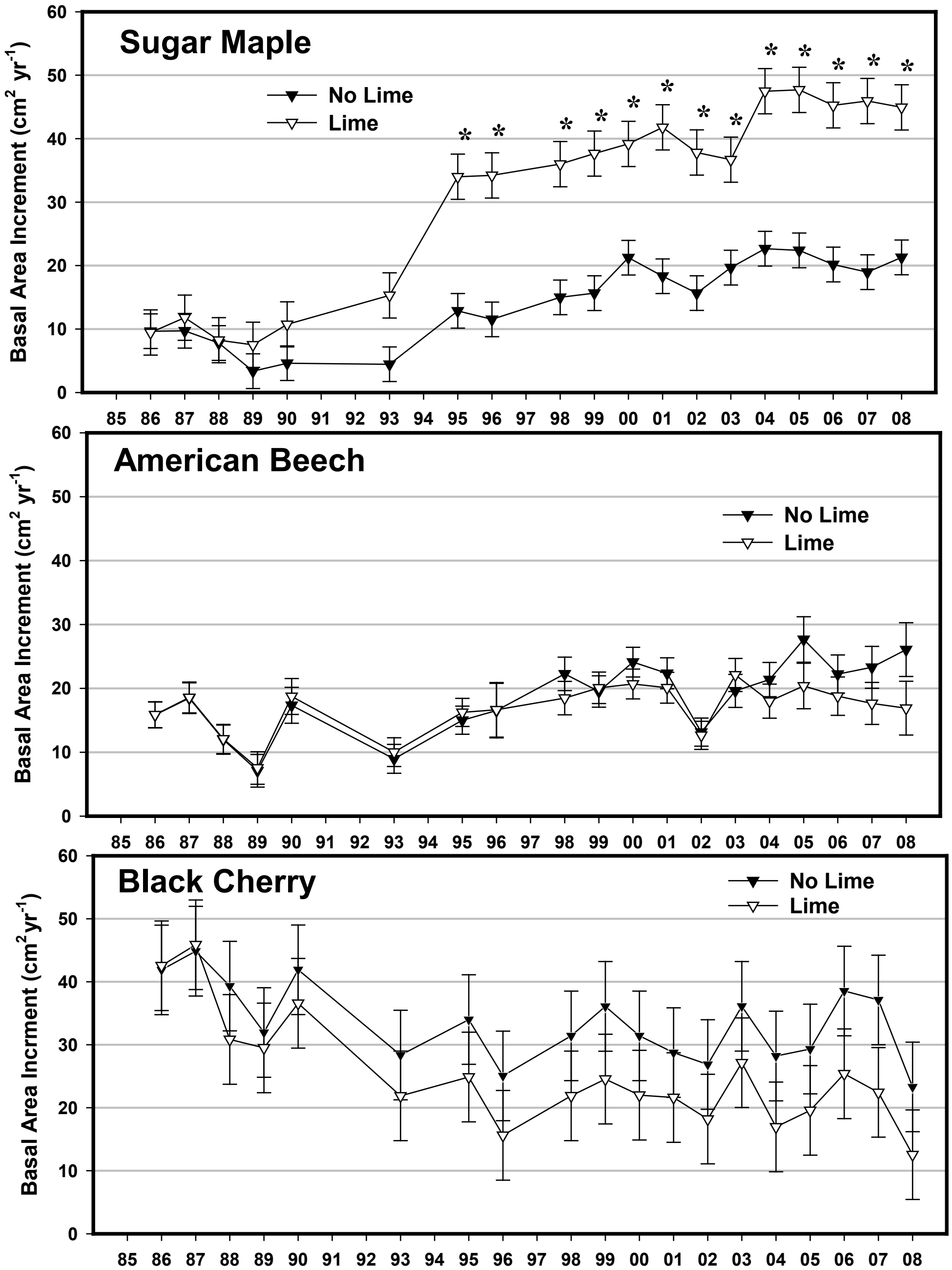

Figure 2.—Least square means of mean annual basal area increment (cm^2 yr^{-1}) for sugar maple, American beech, and black cherry, 1986 to 2008. Asterisks indicate a significant (P ≤0.05) pairwise difference based on the Tukey-Kramer adjustment for multiple comparisons because of year x lime treatment interaction. Pairwise comparisons were not significantly different for American beech or black cherry, but black cherry BAI averaged across all time periods was 25.3 cm^2 yr^{-1} in limed plots, significantly (P = 0.026) less than the BAI of 33.4 cm^2 yr^{-1} in unlimed plots.

Growth Responses

The long-term impact of a single 22.4 Mg ha^{-1} application of dolomitic lime remained evident in 2008, 23 years after its application, in these four northern hardwood stands (Fig. 2). Major effects of the lime treatment were the sustained increase in sugar maple basal area increment (BAI) in limed plots compared with unlimed plots and the detection of a negative growth response of black cherry to lime application. American beech growth was unaffected by lime treatment.

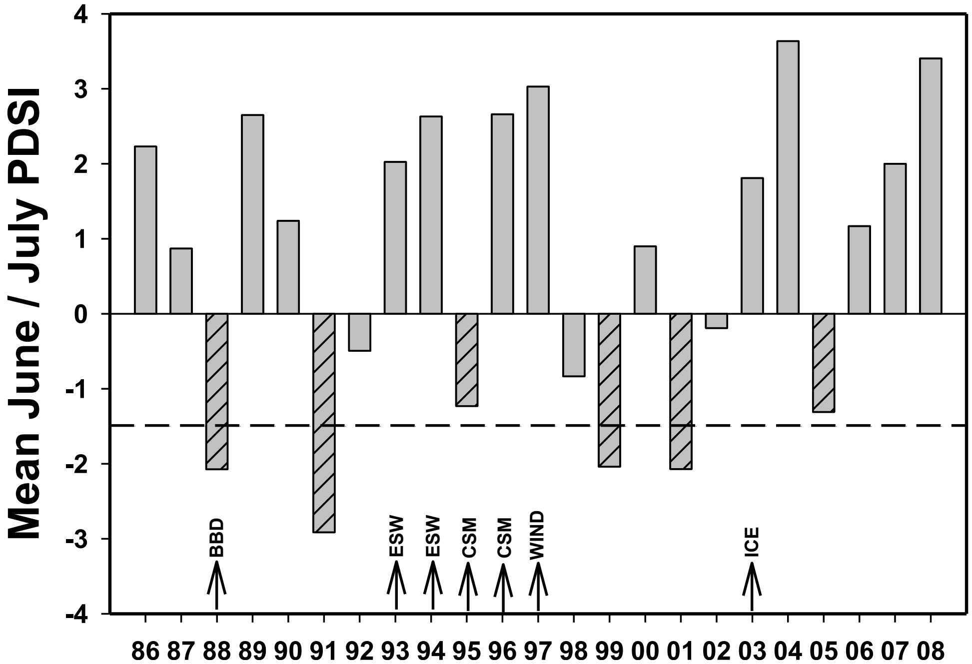

Figure 3.—Disturbance diagram showing drought (mean June-July PDSI for Pennsylvania climate division 10), disease (BBD = beech bark disease initiation), defoliation (ESW = elm spanworm, CSM = cherry scallop shell moth), and ice and wind events affecting the study plots. Dashed horizontal line at −1.5 shows the threshold for mild drought based on the PDSI; cross-hatching on bars shows the years when the PDSI was < −1 (incipient drought).

Average BAI growth for sugar maple trees in limed plots since 2004 has averaged > 40 cm^2 yr^{-1}, a large increase over values observed in the first 8 years of the study when BAI averaged 12.7 cm^2 yr^{-1} for limed trees (Fig. 2) (Long et al. 2011). Sugar maple trees in limed plots have maintained elevated BAI despite the background of disturbance events, which could negatively affect growth (Fig. 3). The droughts of 1988 and 1991 affected crown health and growth, as did the defoliations in 1993 and 1994. Subsequent droughts in 1999 and 2001 were not as severe as the 1991 drought, and no additional defoliations occurred through 2008. As stressors have abated to some degree, limed and unlimed trees have sustained BAI increases, though at a much higher level for limed trees.

American beech BAI (Fig. 2) was unaffected by lime applications, but results may be obscured by the effects of beech bark disease. However, black cherry BAI was negatively affected by lime applications. The negative effect of lime on black cherry growth was not evident in earlier results and may be related to longer-term nutrient imbalances caused by lime application. This result must be interpreted cautiously; black cherry was analyzed on only two of the four replications because of the small number of trees on the other two replications (four remaining black cherry trees on each replication). Black cherry mean BAI on unlimed plots was 33.4 cm^2 yr^{-1}, or 32 percent greater than mean BAI of limed trees, 25.3 cm^2 yr^{-1}.

Although it is tempting to attribute the decrease in black cherry growth to an improved competitive status for sugar maple, on-the-ground observations of stand structure do not support this interpretation. Black cherry remains in a dominant crown position in the two replications where it is abundant. Sugar maples are not noticeably crowded or competing with the black cherry, because the thinning left sufficient room for these trees to continue to grow for some time without directly competing.

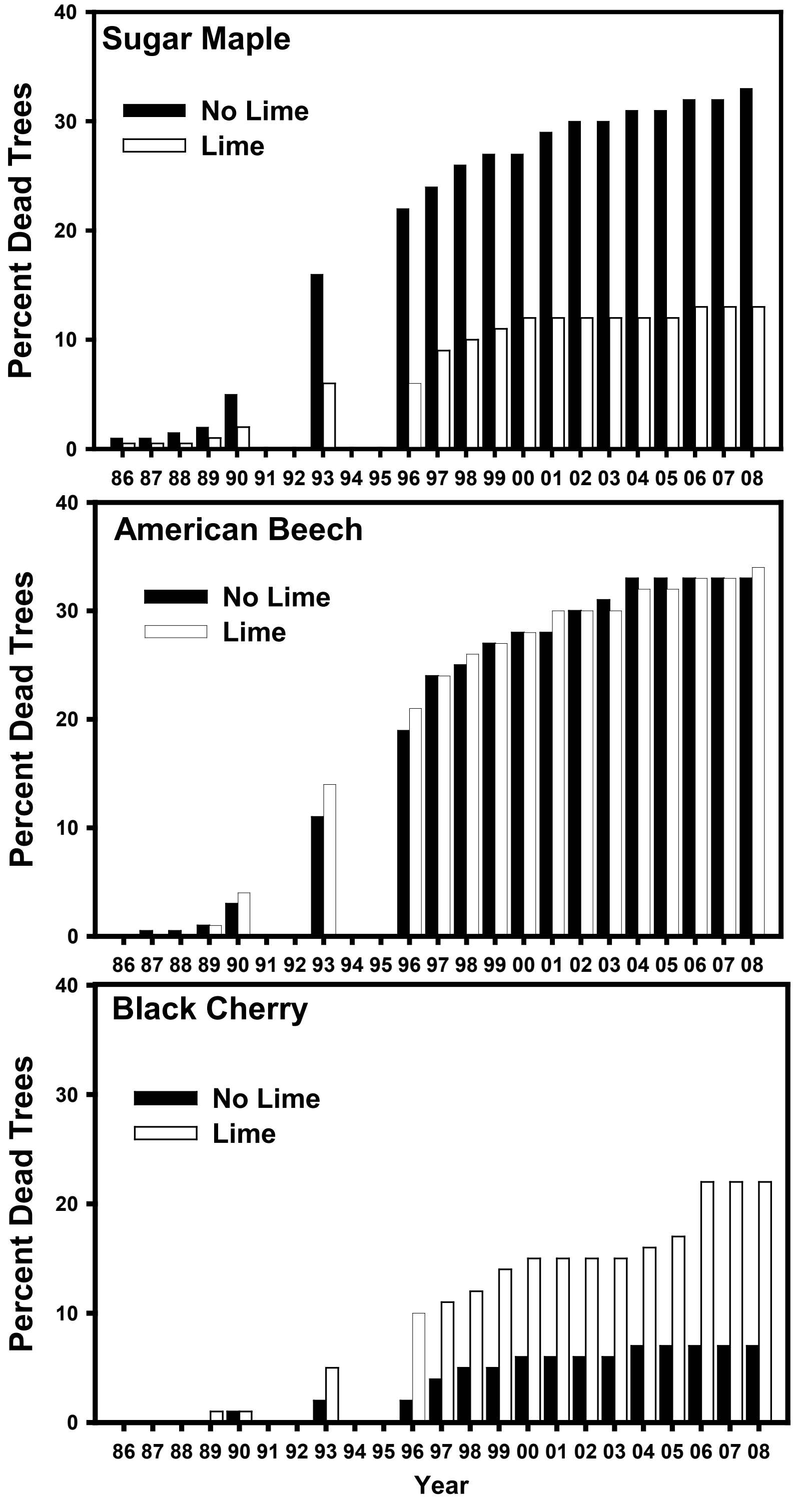

Figure 4.—Cumulative mortality (unadjusted) by year for sugar maple, American beech, and black cherry, 1986–2008.

Mortality

Mortality patterns for all three overstory species show that the highest mortality rate occurred from 1988 to 2001, during multiple droughts and defoliations (Fig. 4). Starting in 2000, the mortality rate leveled off for sugar maple and American beech in limed and unlimed plots but increased abruptly in 2006 for black cherry in limed plots (Fig. 4). Reasons for this increase are not evident but may be related to the drought conditions (mean June–July Palmer drought severity index [PDSI] = −1.31) that prevailed in 2005. Black cherry has been shown to grow less on high base cation sites than on low base cation sites (Long et al. 2009).

Table 1.—Sugar maple and black cherry mean foliage element concentrations in mg kg^{-1} (standard error) and t-test probability levels for comparisons based on means from each block in limed and unlimed plots in 2006

	Sugar Maple			Black Cherry		
Element	No Lime	Lime	T-test Prob. level	No Lime	Lime	T-test Prob. level
Ca	3,913 (191)	9,519 (549)	<0.001	4,952 (72.7)	8,485 (354)	0.010
Mg	646 (39)	2,855 (113)	<0.001	2,279 (1.7)	4,688 (359)	0.094
P	1,140 (61)	1,268 (119)	0.373	1,380 (19)	1,420 (27)	0.343
K	7,657 (204)	6,133 (93)	<0.001	11,821 (1038)	8,226 (753)	0.107
Al	38 (1)	30 (1)	0.002	27 (3)	30 (4)	0.560
Mn	2,946 (221)	426 (76)	<0.001	2,160 (70)	627 (77)	0.005
Fe	59 (4)	44 (1)	0.008	53 (1)	51 (1)	0.175
N	19,329 (356)	18,906 (172)	0.326	23,979 (585)	21,972 (372)	0.101

American beech mortality caused by beech bark disease exceeded 30 percent in limed and unlimed plots during the study (Fig. 4). Sugar maple mortality also exceeded 30 percent on unlimed plots but was only 14 percent on limed plots. Mortality of black cherry remained the lowest of the three overstory species; unlimed plots had the lowest mortality, 6.1 percent, over the 23 years of the study; on limed plots mortality was 21.2 percent (Long et al. 2011).

Foliar Chemistry

Foliar chemistry provides some insights into the differential responses of sugar maple and black cherry in response to liming. The effects of liming on sugar maple foliar chemistry remained apparent in 2006 when the last samples were taken, 21 years after lime application. Increased foliar concentrations of Ca and Mg and reduced concentrations of Al and Mn were maintained for sugar maple foliage from limed trees. Foliar Ca concentrations for limed sugar maples, 21 years after lime application, were 9,519 mg kg^{-1}; foliage from unlimed plots had 3,919 mg kg^{-1}. Similarly, foliar Mg from trees on unlimed plots was 646 mg kg^{-1}, compared with 2,855 mg kg^{-1} for trees in limed plots (Table 1) (Long et al 2011).

In our research, high Mn levels have been associated with decline and poor crown health of sugar maple. High foliar Mn concentration in sugar maple impairs photosynthesis and high late season antioxidant enzyme activity in foliage of dominant and codominant trees (St. Clair et al. 2005). Other cellular symptoms, such as discrete electron-dense areas in the chloroplast thylakoid membranes, delayed transport of starch out of chloroplasts to the roots. Other carbohydrate storage areas may indicate a mechanism for impaired photosynthetic processes (McQuattie and Schier 2000).

In addition to Ca, Mg, Mn, and Al, black cherry may be influenced by N and K. Black cherry foliar N and K levels were reduced by liming in 2006, though differences were not statistically significant (Table 1). Black cherry is a high N-demanding species (Auchmoody 1982). Based on fertilization studies with N-P-K additions in sapling black cherry stands, these reductions of N and K in limed plots may be sufficient to influence black cherry growth (Auchmoody 1982). Although no specific K requirement has been established for black cherry, the lowest foliar K level in untreated sapling stands was 9,200 mg kg^{-1}, which is 1000 mg kg^{-1} higher than observed in foliage from black cherry in limed plots. Similarly, the lowest N concentration from untreated sapling black cherry foliage was 24,300 mg kg^{-1}, and black cherry foliage in our limed plots was about 22,000 mg kg^{-1} in 2006. Deficiencies of N and K in limed plots may account for the reduced black cherry growth.

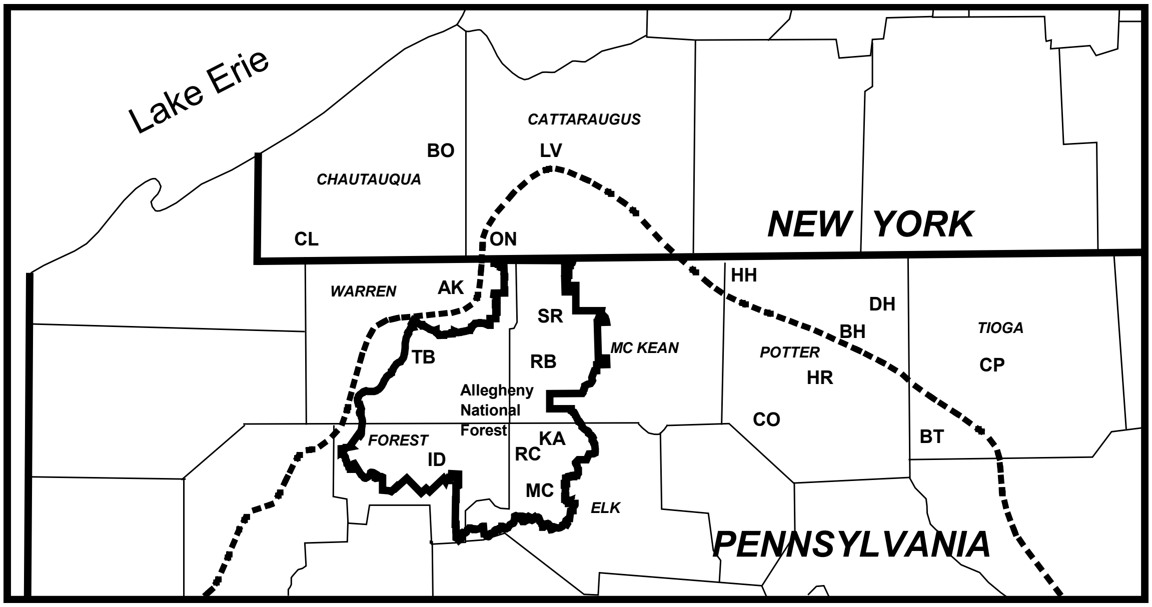

Figure 5.—Location of study sites in northwestern Pennsylvania and southwestern New York. The dashed line represents the southern extent of the Wisconsin glacial advances in the area. Study sites: AK = Akeley, BH = Baldwin Hollow, BO = Boutwell Hill, BT = Brooks Trail, CL = Clymer, CO = Costello, CP = Colton Point, DH = Dodge Hollow, HH = Hemlock Hollow, HR = Hardwood Ridge Trail, ID = Indian Doctor, KA = Kane Experimental Forest, LV = Little Valley, MC = Mill Creek, ON = Onoville, RB = Red Bridge, RC = Russell City, SR = Sugar Run, TB = Tanbark Trail.

Each of the three principal overstory species responded differently to the lime treatment. Sugar maple benefitted from liming with improved crown condition, BAI growth, and survivorship compared with trees in unlimed plots (Long et al. 2011). American beech BAI and crown condition were unaffected by the lime treatment, and beech bark disease resulted in significant beech mortality in limed and unlimed plots. Black cherry had a negative response to liming with lower BAI growth and greater mortality for trees in limed plots compared with black cherry in unlimed plots. Liming proved beneficial for sugar maple but, as shown in this study, different species respond differently to the changing soil chemical environment.

Sugar Maple Health and Growth along Topographic Gradients

Based on our early findings from the lime study and input from foresters and other researchers, Horsley et al. (2000) initiated a study in 1995 to determine how Ca and Mg were distributed in sugar maple stands across an 18 000-km^2 area in northern Pennsylvania and southwestern New York. The influence of glaciation, topographic position, foliar chemistry, defoliation history, and stand characteristics (species composition, structure, and density) on the health of sugar maple was evaluated in 43 stands at 19 sites from Chautauqua County, New York, in the west to Tioga County, Pennsylvania, in the east (Fig. 5). These stands span a wide range of soil parent materials and geologic influences found on the Allegheny Plateau. At each site, two or three stands were sampled along the local elevational distribution of sugar maple. In each stand, five dominant or codominant sugar maples, presumed healthy by lack of symptoms of crown dieback, were selected for foliage sampling. Foliar chemistry of healthy trees was used as a bioassay of site nutritional quality because of its ability to integrate horizontal and vertical differences in soil nutrition within stands. Foliar chemistry was determined for each tree and averaged by stand. Three 0.1-acre sampling plots were established to assess stand composition and tree health. Defoliation incidence and severity were determined for each stand for the most recent 10-year period from 1987 to 1996. Annual

Table 2.—Sugar maple foliar concentrations (mg kg $^{-1}$) of Ca, Mg, Al, and Mn (standard error of the mean) by physiographic position for 43 stands on glaciated and unglaciated sites. n = number of stands represented by each mean.

	Physiographic position				
Element	Summit/ shoulder	Upper back	Mid-back	Lower back	Enriched
	Glaciated sites				
	n = 2	n = 4	n = 2	n = 3	n = 7
Ca	11 800	9300	11 100	7800	9600
	(2000)	(2900)	(2000)	(300)	(1100)
Mg	1160	1160	1290	1110	1380
	(90)	(170)	(200)	(70)	(100)
Al	26	38	26	30	30
	(4)	(8)	(4)	(5)	(5)
Mn	1780	1690	1270	1220	1140
	(10)	(350)	(220)	(170)	(60)
	Unglaciated sites				
	n = 9	n = 3	n = 3	n = 3	n = 7
Ca	4500	7300	7100	9400	8800
	(300)	(2500)	(1200)	(2100)	(900)
Mg	630	1150	1060	1170	1260
	(60)	(250)	(180)	(60)	(100)
Al	37	28	23	24	29
	(2)	(5)	(2)	(1)	(4)
Mn	2770	1740	1720	1220	1280
	(170)	(310)	(340)	(120)	(200)

layers of digitized sketch maps were used to determine the timing, agent, and severity of defoliation and allowed development of a defoliation severity index (DSI) for each stand. One representative soil pit was sampled in each stand using Soil Survey Staff (1993) protocols. Pedons were sampled to at least 130 cm, unless bedrock was encountered at a shallower depth (Bailey et al. 2004). Root density, depth to a root-restricting layer, and depth to redoximorphic features were recorded for each soil pit. Soil samples for chemical analyses were collected by genetic horizon and were analyzed to determine pH, exchangeable cations (Ca, Mg, Na, and K), and exchangeable Al and acidity (see Bailey et al. 2004 for details).

We used percent dead sugar maple basal area (%DEADSM) as the measure of health and found that all moderately to severely declining stands were on unglaciated summits, shoulders, or upper backslopes. Stands on glaciated sites and unglaciated lower topographic positions were not declining when evaluated in this study. Foliar nutrients, particularly of Ca, Mg, and Mn, and defoliation stress during the preceding 10 years, were the most important factors associated with sugar maple health. The lowest foliar Mg, highest foliar Mn, and highest number and severity of insect defoliations were associated with stands on unglaciated summits, shoulders, and upper backslopes (Table 2). Across the sampled region, glaciation, topographic and physiographic position, and elevation were surrogates for foliar nutrition of Ca and Mg and appear to delineate landscape positions with inadequate base cation supply where sugar maple may be vulnerable to other stressors. All six stands with unhealthy sugar maple (> 22 percent %DEADSM) were associated with unglaciated landscapes on summits,

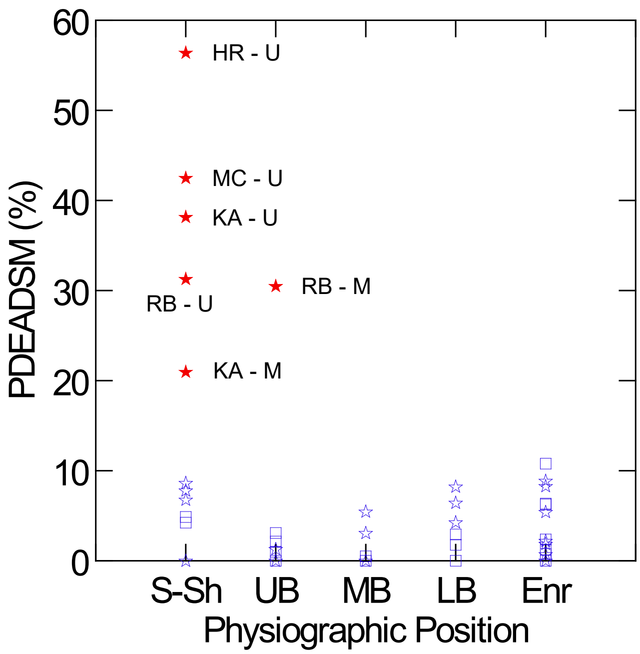

Figure 6.—Relationship between sugar maple health as measured by %DEADSM and stand physiographic position. S-Sh = summit and shoulder, UB = upper backslope, MB = mid-backslope, LB = lower backslope, Enr = enriched sites including benches, seeps, and concave microtopography. Stars represent stands on unglaciated sites. Squares represent stands on glaciated sites. Unfilled symbols represent nondeclining stands. Filled symbols represent stands with moderate to severe decline.

shoulders, and upper back slopes (Fig. 6). Competitive stressors caused by stand conditions had relatively little effect on stand health. Declining stands had < ~700 mg kg^{-1} Mg and two or more moderate to severe defoliations in the past 10 years. The results suggest the importance of base cations, particularly Mg, for health of sugar maple (Horsley et al. 2000) and point to a potential role for Mn toxicity. Mn toxicity was identified in the late 1990s as a factor associated with sugar maple decline (Timmer and Teng 1999).

Disturbance caused by insect defoliation was an important inciting stressor in this study. Both the number of defoliation events in the preceding 10 years and the DSI (1 = light defoliation, 2 = moderate defoliation, and 3 = heavy/severe defoliation) were significantly related to %DEADSM; the DSI for the previous decade produced the strongest relationships with %DEADSM. There was a relationship between defoliation history, as measured by the number of defoliation events and the defoliation severity index (DSI), and sugar maple health; the strongest relationship was between %DEADSM and DSI for the 10 years preceding health evaluation (R^2 = 0.158, p = 0.008). Moderately to severely declining stands had two or more defoliations in the previous 10 years with a DSI ≥ 4, equivalent to two moderate defoliations (Fig. 7A). However, some stands with these defoliation history criteria were classified as nondeclining. These stands were located on glaciated areas and on upper (U), mid (M) or lower (L) slope positions (BH-L, CL-U, CL-M, CL-L, CP-U, DH-U, DH-M, DH-L), unglaciated lower backslopes (MC-L), unglaciated areas with seeps (RC-L, SR-U), or unglaciated areas with concave microtopography (KA-L) (Fig. 5). Only one stand, RC-U, did not fit these descriptions; it had been thinned in the preceding 10 years.

There was evidence of an interaction between foliar Mg and defoliation history. All stands in which sugar maple was moderately or severely declining had in common foliar Mg < ~700 mg kg^{-1} and ≥2 moderate or severe defoliations (DSI ≥ 4) during the 10 years before the health evaluation (Fig. 7B). Nondeclining sugar maple were associated with foliar Mg ≥ ~ 700 mg kg^{-1} and, even with frequent and severe defoliations, did not develop symptoms of decline. Some stands with as many as four defoliation events in the 10 years before health evaluation were classified as nondeclining. Sugar maple in these stands had foliar Mg ≥700 mg kg^{-1}. Similarly, stands with a DSI as high as 6 for the 10 years before health evaluation had values of %DEADSM, which were classified as nondeclining; sugar maple in these stands also had foliar Mg ≥700 mg kg^{-1} (Fig. 7B).

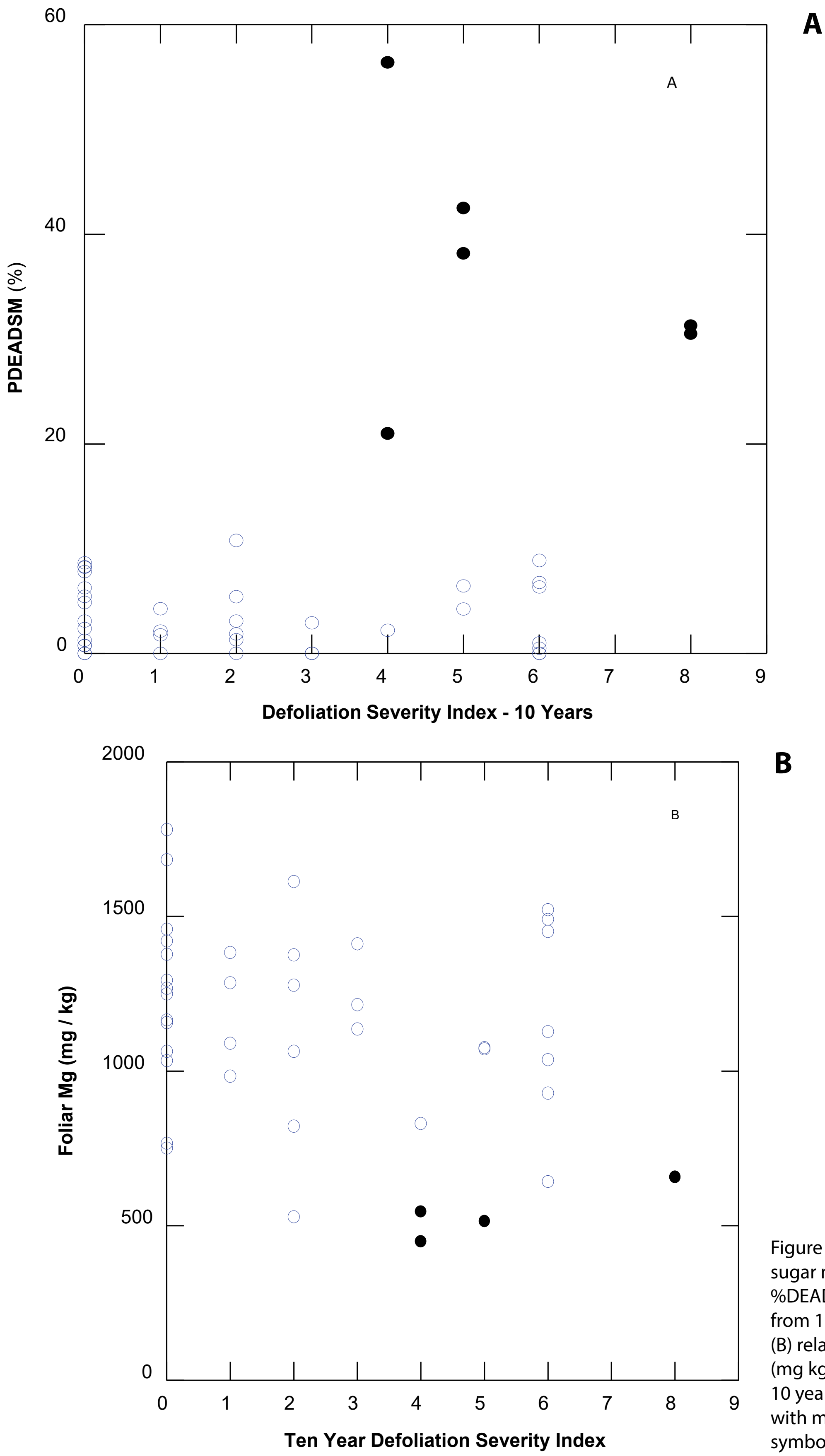

Figure 7.—(A) Relationship between sugar maple health as measured by %DEADSM and the DSI in the 10 years from 1987 to 1996 (R^2 = 0.158, P = 0.008); (B) relationship between foliar Mg (mg kg^{-1}) and the DSI for the previous 10 years. Solid symbols show stands with moderate to severe decline. Open symbols show nondeclining stands.

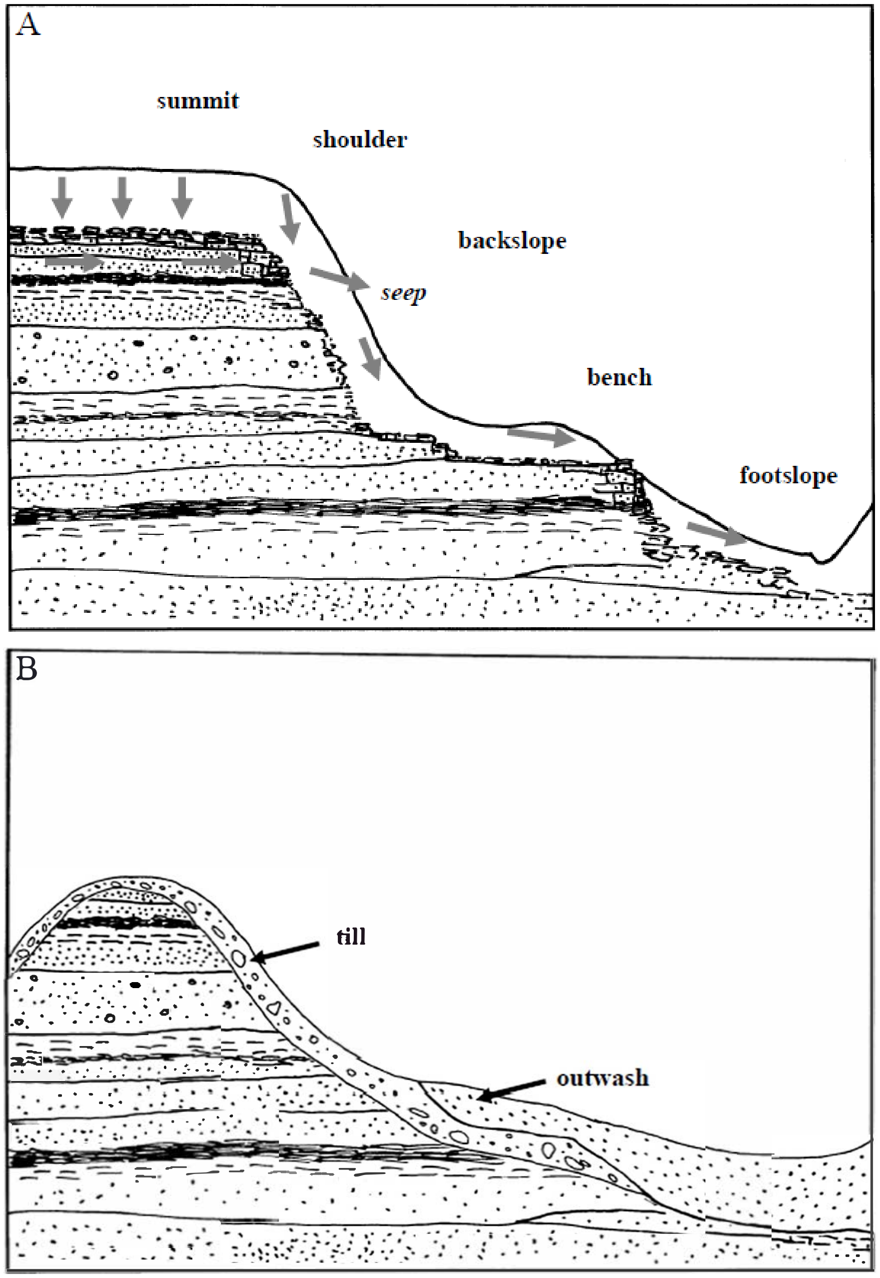

Figure 8.—Schematic cross sections of (A) unglaciated and (B) glaciated portions of the Allegheny Plateau. Patterned areas represent interbedded sandstone, siltstone, and shale bedrock. Soils on the unglaciated section are developed in relatively thick, weathered residuum, colluvium, and alluvium shown as the unpatterned area above the bedrock. Arrows suggest general direction of water flow in unglaciated soils and bedrock. Soils on the glaciated section are developed in relatively unweathered glacial till and outwash.

Foliar Ca and Mg were significantly correlated with many soil variables. Soil base saturation, which was dominated by Ca and Mg because of low concentrations of Na and K, also showed significant correlations with foliage values. The best predictors of foliar chemistry were made by regressions that considered soil chemistry across the depth of the B horizon, suggesting the importance of looking at more than one depth to assess nutrition (Bailey et al. 2004).

An important aspect of the soils research highlighted the differences between glaciated and unglaciated soils. On unglaciated sites, particularly on upper landscape positions, weatherable minerals are confined to the lower parts of the regolith well below the rooting zone, or within underlying bedrock. Thus, the delivery of weathering products, such as Ca or Mg ions, to the rooting zone is limited to parts of the landscape where water flow paths bring ions released from bedrock or deeper regolith to the solum where roots are active (Fig. 8A) (Bailey et al. 2004). In contrast, on glaciated portions of the Allegheny Plateau, much of the weathered regolith was removed by glacial erosion (Fig. 8B). Soil developed in glacial till incorporates relatively unweathered material freshly exposed by glacial erosion. Thus, weathering reactions occur within the rooting zone and create less contrast in base cation levels by landscape position (Bailey et al. 2004).

These findings allowed for a more explicit application of Manion's decline spiral model (Manion 1991). Site nutrition, as influenced by glaciation and landscape position, affects the availability of Ca, Mg, and Mn. Thus, poor base cation nutrition is a predisposing factor that makes sugar maple more susceptible to decline. Insect defoliations and other less well-quantified stressors such as drought are the inciting factors that cause crown dieback and mortality for susceptible trees. For sugar maple, contributing stressors (the actual mortality agents) included *Armillaria* fungi, the sugar maple borer (*Glycobius speciosus*), and other organisms (Hallett et al. 2006, Horsley et al. 2002).

Long-term Changes in Forest Soil Chemistry

Why did sugar maple decline occur during the late 1980s and early 1990s? The conceptual decline model described above relates the sequence of stressors that affected sugar maple health and mortality during this period. However, the timing of the decline coincident with the high levels of acid deposition inputs suggested that losses from these soils could have affected soil base cation status and sugar maple health. To assess changes in forest soils, we conducted a unique retrospective study that used archived soils sampled in 1967 from four forested sites on the Allegheny National Forest along with new contemporary samples (Bailey et al. 2005). In 1997, four new pits were established 10 m north, south, east, and west of the original 1967 pit. These were sampled by genetic horizon to 1 m or greater depth at each site to assess spatial variability and to compare long-term changes in soil base status. All four sites supported mature fully stocked second- and third-growth northern hardwood or mixed-oak forests that originated following forest removal between 1890 and 1930 (Marquis 1975). All sites were in the plateau top physiographic position near the local height of land and had been mostly undisturbed (no active management) since the 1960s.

The 1967 soils were subsampled and reanalyzed with contemporary analytical methods, and results were compared with the original 1967 analyses. Comparisons to 1967 showed a slightly lower pH in reanalyzed samples, but there was still a high correlation between the two ($r = 0.87$). Ca, Mg, and Al concentrations in reanalyzed 1967 samples were highly correlated with the original values with all correlations >0.92 (Bailey et al. 2005).

Comparisons of 1967 archived soils and 1997 soil samples showed long-term decreases in pH, exchangeable Ca and Mg, and increased exchangeable Al (Fig. 9) (Bailey et al. 2005). Changes in pH and exchangeable Ca and Mg were evident at all depths sampled up to 150 cm; changes in Al were mainly in the upper 30 to 50 cm (Bailey et al. 2005). Soil pools of Ca, Mg, and Al were calculated based on measured cation concentrations, horizon thickness, volumetric rock content, and bulk density. Values from the 1967 pits were similarly calculated for comparisons. We used three 400-m^2 vegetation plots at each site to estimate biomass storage of Ca and Mg in all trees 10 cm diameter at breast height and larger in 1997. We also used equations compiled by Jenkins et al. (2003) to divide biomass of each tree into foliage, stem wood, stem bark, branches, and coarse roots. The biomass storage in 1967 was estimated using data from eight fully stocked stands in a thinning study to estimate growth rates (Nowak 1996). We used the growth data to estimate the tree diameters in our plots in 1967 and then calculated the amounts of Ca and Mg stored in the biomass in 1967. This amount was then subtracted from the 1997 biomass values to provide the amount of Ca and Mg stored in trees from 1967 to 1997 (Bailey et al. 2005). The difference between the 1997 and 1967 biomass Ca and Mg represented a conservative estimate of what was sequestered in trees over 30 years.

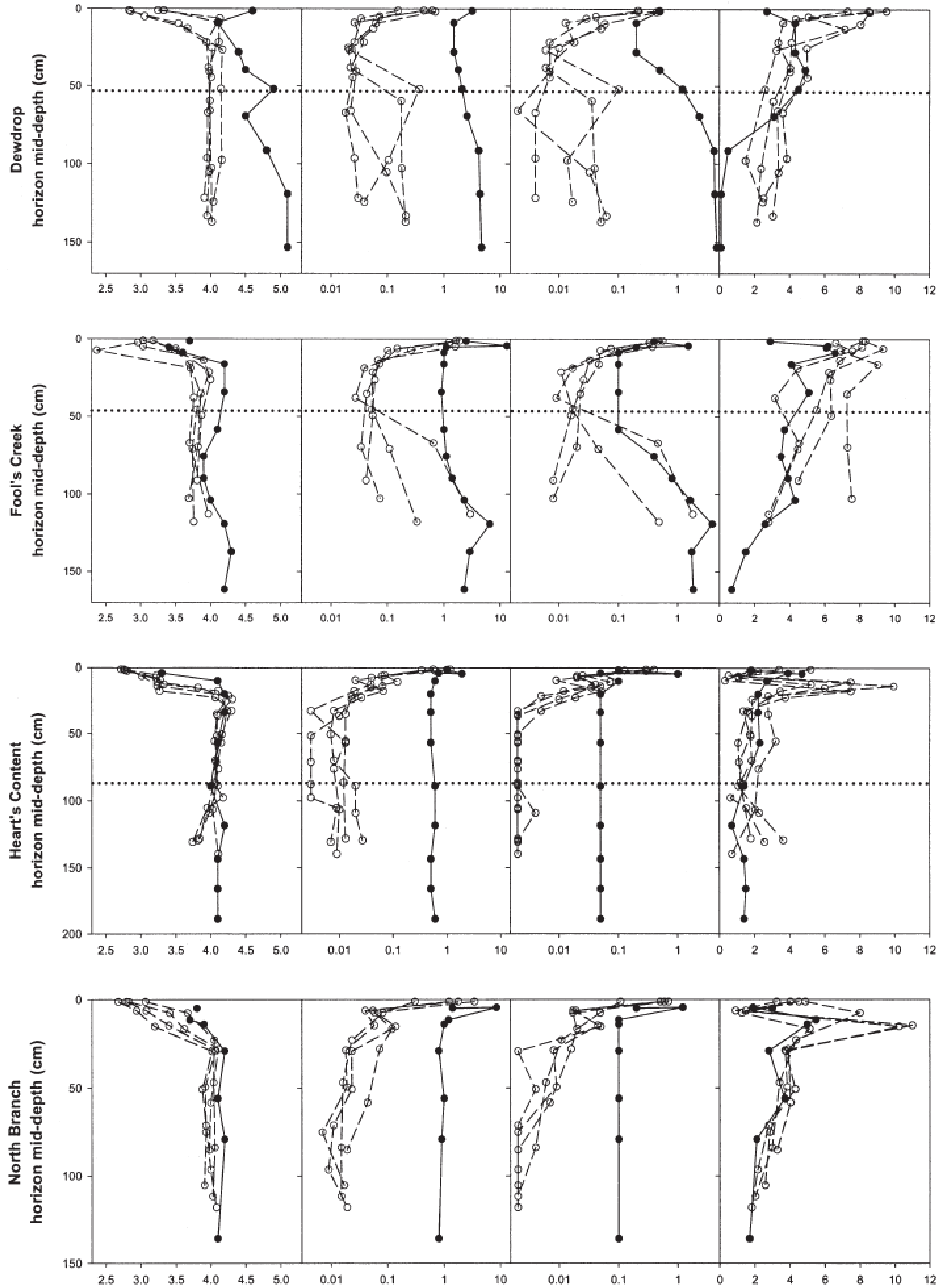

Figure 9.—Depth profiles of pH (standard units) and exchangeable Ca, Mg, and Al (cmol$_c$ kg^{-1}) at each of four study sites. The closed circles represent the data collected from the original pit dug in 1967. The open circles represent the data collected from four pits dug in 1997, located 10 m from the original pit, in each of the four cardinal directions. The dotted horizontal line shows the average depth of the top of the fragipan, where present. A fragipan was found at three of the five pits at DD, all five pits at FC, and one of the five pits at HC.

Comparison of soil pool changes with net biomass accumulation suggest that many of the changes in exchangeable Ca and Mg in these soils cannot be accounted for by forest growth, implying off-site leaching (Bailey et al. 2005). These findings were consistent with those from other studies that found acid deposition induced significant losses of exchangeable base cation pools by hydrologic leaching (Fernandez et al. 2003, Huntington et al. 2000, Likens et al. 1996).

Because deposition inputs vary from year to year, we also examined short-term temporal variation by sampling forest floor organic layers (Oi, Oe, Oa/A) over 3 years (1997–99) at all four sites. The very thin Oa horizons could not be sampled separately, so Oa and A horizons were combined for analyses. Overall, short-term variability was minor and within an expected range. Changes between 1997 and 1999 samples were slight compared with values in 1967. As in the deeper mineral soils, pH was much lower, about 3.0 in 1997–99 samples compared with 1967 pH about 4.0. Similarly, Ca and Mg were much lower in 1997–99 organic layers compared with 1967 concentrations. Al concentrations were much higher in 1999–97 organic layers than in 1967 concentrations (Bailey et al. 2005).

This unique study showed that changes in soil base cation status and acidity over 30 years was a predisposing stressor for sugar maple and likely accounts for the timing of the maple decline in the late 1980s and 1990s. The addition of inciting stressors such as defoliating insects added the critical components that caused sugar maple crowns to die back and for trees to die from attacks by secondary organisms.

CONCLUSIONS

Our studies in Pennsylvania, New York, and New England over more than a decade led to new insights regarding sugar maple health and nutrition. A key aspect of this research was the multidisciplinary team that conducted the research. The scientific collaboration across the disciplines of soil science and geology, forest ecology, plant physiology, and forest pathology accelerated progress in understanding the causes of sugar maple decline. Each scientist brought unique skills and expertise that enabled us to synthesize the factors that affected sugar maple health and led to substantial new findings. A key lesson is that diverse levels of scientific expertise accelerate the achievement of new knowledge and understanding.

Along with this work, guidelines and tools for land managers were developed. These included:

- Choose appropriate sites to culture sugar maple—sites with adequate Ca and Mg.
- Use indicator plants to help select sites with adequate Ca and Mg nutrition (see Horsley et al. 2008).
- Monitor and record stressor events and their effects—especially defoliations and droughts.
- Supplement nutrition—consider adding lime where feasible.
- Protect base cations on sensitive sites—leave treetops and don't fertilize to conserve Ca and Mg.
- On low base cation sites, emphasize species that are not responsive to base cations—for example, red maple and black cherry.

The lime study findings in the mid-1990s were important for identifying the key role of base cation nutrition for sustaining sugar maple health, even when trees were stressed by defoliations and drought. The differential responses of American beech and black cherry also highlight the complexity of forest nutrient and tree growth interactions and that nutrient requirements vary by species. The gradient study was initially a pilot project to determine how Ca and Mg were distributed on the landscape and whether this was related to sugar maple health. Expanding this work across a broader geographic area and gathering additional stand history information keyed us to the finding that glaciation, landscape position, and the number and severity of defoliations were important factors in determining where on the landscape sugar maple was most likely to decline. Initial findings that Ca and Mg were lowest on unglaciated upper landscape positions and that these were the sites with the most sugar maple mortality led to more intensive assessment of soil nutrition at all 43 stands. Understanding the critical influence of bedrock parent materials and hydrologic flow paths on unglaciated sites helped explain the site variability that affected changes in sugar maple health. The retrospective soil nutrient study used four sites on the Allegheny National Forest and showed substantial losses of Ca and Mg throughout the soil profile from 1967 to 1997 as a result of deposition inputs. Base cation losses and soil acidification likely influenced the timing of the sugar maple decline. The stressors affecting sugar maple came together in the mid- and late 1980s and caused extensive dieback and mortality. However, since this period, deposition inputs have decreased, and insect defoliations have been less frequent. These factors allow many sugar maples to survive and recover.

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NED AND SILVAH: A HISTORY OF THE COALITION

Mark J. Twery[1]

Insights for Managers

- **When SILVAH data are read into NED-3, they can produce lists of wildlife species that are likely to find suitable habitat in the stand represented by those data.**
- **SILVAH data can be interpreted from a water quality, aesthetic, or forest health perspective.**
- **NED users can essentially run SILVAH on their data from within the NED framework to provide access to the expert prescriptions available from SILVAH when their stands are of the forest types well served by SILVAH.**

INTRODUCTION

Forest management decision support software has been used for several decades. Many people have tried a variety of approaches, with varying degrees of success, to provide information that helps forest managers make decisions. This chapter documents some of the successes and failures of NED and SILVAH.

In 1988 the U.S. Department of Agriculture, Forest Service Northeastern Forest Experiment Station used its Genesis program to stimulate innovation. Under the leadership of H. Clay Smith, it convened the Stand Regeneration working group and, under the leadership of David Marquis, created the Stand Growth working group. Before that time, silvicultural research across the station had been scattered; each local researcher worked independently, which resulted in a variety of growth models and approaches to silvicultural analysis and prescription. The Genesis working groups used the SILVAH system of inventory, analysis, and prescription as a model to consolidate much of the silvicultural research that had been produced by scientists across the station's territory (Benzie 1977a, 1977b; Dale and Hilt 1989; Frank and Bjorkbom 1973; Lancaster 1985; Lancaster and Leak 1978, Leak et al. 1969, 1987; Perala 1977; Philbrook et al. 1973; Roach 1977; Safford 1983; Stout and Nyland 1986; Stout et al. 1987). The idea was to develop a software package that would provide a universal framework for sharing silvicultural research results and proposing recommended actions. The first step was to develop a software package that consolidated several growth models that had been developed independently around the northeastern United States, including SILVAH (Marquis and Ernst 1992), NE-TWIGS (Teck and Hilt 1991), Fiber (Solomon et al. 1995), and Oaksim (Hilt 1985). This software package was called the Northeast Decision Model, or later NED.

The Northeast Decision Model began as an effort to help foresters manage their various forest types for timber production, but the developers recognized the growing concern among forest managers who needed to manage for additional benefits, including wildlife habitat, water production and protection, recreation, visual qualities, and forest health. This recognition induced the recruitment of experts in each specialty the model needed to address.

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The coalition of interested parties expanded NED through outreach to include resource specialists from the various state agencies in Pennsylvania, New York, New England, and the Lake States, among others. National forest managers in the region also volunteered to participate, as did private consulting foresters and researchers from a variety of universities.

In the summer of 1990 David Marquis and H. Clay Smith convened a large group of researchers and practitioners in the various fields for a field tour in Pennsylvania and West Virginia. The group originated with the Stand Culture and Stand Regeneration working groups and included silviculturists, wildlife biologists, landscape architects, social scientists, hydrologists, and ecologists. During this trip, participants discussed the conditions that were needed to provide wildlife habitat for species of interest, the aesthetic qualities of slash piles, the maintenance of water quality, and other topics.

The underlying assumption was that by manipulating vegetation through silvicultural activity, a forester could affect conditions in the forest. The right conditions could, in turn, increase or decrease the likelihood that a specific goal would be met, whether that goal was for timber, wildlife habitat, recreational aesthetics, or water production. The entire group recognized the need to find a common set of terms by which they could describe the conditions necessary to meet the goals of their specialties. Once defined in terms that could be evaluated from a forest inventory, the design was to create a computer program to help managers develop scenarios that would create the conditions that met their needs. It was readily apparent that a single committee could not efficiently accomplish the work related to so many disciplines, so the group subdivided into expert committees. At the same time, the need for a common framework and vocabulary necessitated a steering committee whose members would help each disciplinary committee use the common terms and concepts consistently.

At the end of 1991 David Marquis retired, and leadership of NED passed to Mark Twery, another USDA Forest Service Northeastern Research Station scientist.

NED is a set of decision support tools designed for the analysis of integrated prescriptions for managing forests for values up to a landscape scale. It is organized around four steps for creating management plans:

1. Define the goals for managing a property.
2. Collect data to determine current conditions on the property.
3. Analyze the data to compare current with desired conditions to develop prospective prescriptions to achieve the management goals.
4. Compare simulations of forest development under a variety of prescriptions to determine which scenario is most likely to achieve the identified goals.

From its beginnings in the late 1980s and early 1990s, NED differed from SILVAH in several ways:

- NED explicitly included multiple values and disciplines.
- NED allowed for inclusion of multiple stands and some consideration of spatial arrangement of those stands on and in a landscape.
- NED covered many more forest types than SILVAH.

SILVAH still offered explicit expert silvicultural prescriptions to optimize timber growth and ensure diverse regeneration for a narrower range of forest types.

EARLY DEVELOPMENT

The NED team created a program known as NED/SIPS, the Northeast Decision Model Stand Inventory Processor and Simulator (Simpson et al. 1995). This program ran in DOS and enabled consulting foresters to summarize inventories and analyze potential growth of timber for an individual stand. NED/SIPS borrowed heavily from SILVAH (Marquis and Ernst 1992) in philosophy and format, but it did not include the expert system function in which SILVAH advises the user on the right action for a particular stand (Marquis et al. 1992). Many consulting foresters in the Northeast adopted NED/SIPS; however, it was of limited utility to public land foresters and others who needed to evaluate management across resources and across a landscape because it did not address other resources.

In parallel with NED/SIPS, the team began to develop a program to incorporate the knowledge gleaned from the various disciplinary expert committees. This program became known as the Forest Stewardship Planning Guide (FSPG) (Alban et al. 1995). FSPG and all subsequent programs were developed in the Microsoft Windows® environment. The target users were consulting foresters and private landowners, who together could use the program to help clarify the landowner's goals and identify which resources could be managed at the same time on the same piece of land, and which needed to be separated in either time or space. However, FSPG was built simply to evaluate alternatives in principle without incorporating field data from a forest inventory. FSPG did find use among consulting foresters in the Northeast, and it became commonly used in introductory forestry programs at schools around the region.

An additional stand-alone program to evaluate wildlife habitat took form at this time. Known as NEWILD (Thomasma et al. 1998), the information previously published by DeGraaf et al. (1992) in book form was converted into rules that could be evaluated in the computer based on the forest inventories. The creation of new inventory guidelines that included characteristics not usually addressed by foresters but necessary or useful for evaluating habitat (shrub cover, litter cover, high perches, etc.) was another outcome of NED development during this period, based on work by Cleveland and Finley (1998). One key innovation of NEWILD was the presentation of lists of wildlife species with potential habitat in any stand based directly on foresters' inventories.

NED-Health was another program developed as a component of the NED project. It provides information on stress agents such as insects, fungi, weather, and people, that affect the health of the trees within a forest. The program analyzed the composition of a specific forest and identified potential causes of damage, methods to recognize specific agents, and possible actions to avoid or mitigate damage. It was built from a single screen much like that of NEWILD, but it added a screen to allow display of several information options. Although identified as potentially useful information, the resources available could not keep up with the changing world of pests and forest health issues, and the program never received wide distribution. Its resources continued to be available in other subsequently developed programs, however.

The next step in development, to incorporate field data from an inventory on a multiple-stand property and evaluate these data for multiple resources, occupied the late 1990s and resulted in the program known as NED-1 (Twery et al. 1998, 2000). NED-1 created the context in which to incorporate the rules developed by each disciplinary expert committee and evaluate them in the context of the other resources. See, for example, analysis of water goals in the context of forest management presented by Twery and Hornbeck (2001). The wildlife habitat analysis structure used in NEWILD was developed using Cleveland and Finley's (1998) rules for Pennsylvania and incorporated into NED-1. Because the tasks of integrating multiple resources into a unified analysis across multiple forest stands were complex, we decided to delay incorporating growth simulation in the combined model. At this point development expanded to include researchers and practitioners from outside the northeastern United States, and the name of the effort changed from the Northeast Decision Model to NED.

CONTINUING DEVELOPMENT

Geographical expansion of NED centered around the southeastern United States; key players included Michael Rauscher of the Southern Research Station and Donald Nute and Walter Potter of the Artificial Intelligence Institute at the University of Georgia. Through this collaboration, we developed a structure to integrate the goals of forest inventories with a method by which we could analyze the degree to which goals were likely to be met under a variety of conditions (Nute et al. 2002, 2004; Rauscher et al. 2000, 2001). This work developed into the program NED-2 and used PROLOG as a basic framework for handling the artificial intelligence needed to manage the integration.

We determined that the best way to integrate treatments and growth simulation into the program would be to use a well-supported simulator, so we chose the Forest Vegetation Simulator (FVS) (Crookston and Dixon 2005). We could thus implement simulated treatments and use a variety of growth models to project development of the forest stands. The NED development team used FVS as the engine behind the scenes to create its own interface within the NED-2 system to design and schedule treatments and implement growth projections (Wang et al. 2002).

Other side projects that sprang from the NED development work included Stewplan, (Knopp and Twery 2003), which attempted to provide a template for consulting foresters to generate stewardship plans that conformed to standards that allowed private forest landholdings to participate in cost-share programs. Stewplan was successfully distributed to consulting foresters and state service foresters throughout the region, and some states adopted policies accepting a Stewplan report as a valid format for their stewardship plans.

Another related development effort was NED-Lite (Knopp and Twery 2006), which was developed as way to allow electronic data entry to be performed on handheld devices in the field. This saved time and eliminated transcription errors in the process of copying data from paper field sheets into the computer. NED-Lite was developed for the Palm operating system and achieved a favorable reception among consulting and service foresters, but the Palm system lost popularity, making it difficult to keep up with changing software requirements. NED-Lite was adapted at least partially to the Microsoft CE system for handheld devices and saw further use, but lack of adequate resources relegated this software to use by only a devoted few.

Wildlife habitat analysis continued, and the regions where it was applied continued as the principles and structure of NEWILD were adapted to Pennsylvania, Michigan, and Maryland (Thomasma and Cleveland, 2019).

Development of NED-2 (Twery et al. 2011, 2012) continued through the decade; it became useful in a variety of contexts. Numerous college and university programs around the Northeast adopted it to teach students forest inventory summarization techniques and to analyze alternative management strategies.

NED-2 allowed users to create scenarios of management activities across multiple stands in a management area through time and allowed analysis of conditions at any step. Analysis of a snapshot of conditions allowed evaluation of the degree to which stated goals were being met through comparison of actual or simulated conditions to those identified as desired conditions based on previously assembled expert knowledge and identified goals. One considerable limitation to these analyses was the constraint imposed by the lack of simulation models to project changing conditions other than the standing inventory of trees. For example, abundance and size in the understory of species other than trees are not modeled in existing systems, nor are the times needed for trees that die to progress from snags to down woody material to forest floor organic matter.

These experiences proved useful, both for actually managing forests and for showing the shortcomings of NED-2. One of the primary problems identified was the slow speed at which NED-2 ran simulations. Once this slowness was traced to the use of PROLOG as the controlling software, we determined to rewrite the software without PROLOG, using C++ for all major functions. This change resulted in development of NED-3, which is the current state of the NED software (https://www.nrs.fs.fed.us/tools/ned/). NED-3's improvements include a flexible data import facility, much faster simulation using all variants of FVS, which can be customized from the NED-3 interface, a wider variety of user-selected and user-defined treatments, and an improved report selection interface.

INTEGRATION BETWEEN NED AND SILVAH

Because NED-3 was being developed by the same people who were updating and expanding SILVAH, the development of the two programs could overlap again. The current version of NED-3 can run SILVAH (https://www.nrs.fs.fed.us/tools/silvah7/) directly to generate standard SILVAH output from inventories created using NED data inputs.

Shared resources and shared approaches to addressing multiple management objectives, integrated inventories, and comprehensive analyses allow NED and SILVAH to use each other's development products to good effect. For example, the NED wildlife habitat analyses were relatively easy to incorporate into SILVAH's later versions with minimal adjustment of inventory parameters. SILVAH's expert system advice on next steps in a management scenario has been incorporated into the NED interface directly, because SILVAH on NED inventories can be run within the NED program.

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The content of this paper reflects the views of the author, who is responsible for the facts and accuracy of the information presented herein.

SILVICULTURE AND BIRD HABITAT

Scott H. Stoleson[1]

Insights for Managers

The responses of forest bird communities to silvicultural practices vary with the intensity of treatment and time since treatment. Specifically:

- **Overall abundance and species richness peak several years after harvest in shelterwood cuts and overstory removals, then decline over time.**
- **Bird species that specialize on early-successional woody habitats represent the guild of highest conservation concern in the northeastern states.**
- **Overstory removals support a full suite of early-successional bird species, and shelterwoods a nearly full suite.**
- **Shelterwoods tend to retain most late-successional species.**
- **Habitat requirements of many bird species shift after breeding, with most moving into early-successional habitats.**
- **Uneven-age treatments, such as group or single-tree selection, provide too little shrubby habitat to support more than a few early-successional species.**
- **Different stages of even-age silviculture across a landscape tend to allow for greater conservation of multiple guilds and suites of bird species.**

BACKGROUND

Forests, particularly those on public lands, are managed for multiple resources. Forest resources include timber production, watershed protection, carbon sequestration, recreational opportunities, and wildlife habitat, among many others. For most nonindustrial private landowners, sustaining wildlife ranks higher than timber production as a forest ownership goal (Butler and Leatherberry 2004). Until recently, the SILVAH decision support system included only a very minor wildlife component, the ability to record stems as actual or potential den trees (Marquis et al. 1992). Wildlife information has been included in SILVAH training sessions in three ways:

- As part of the forest ecology background.
- As wildlife management suggestions within the SILVAH framework.
- As a synthesis of the effects of various management actions on wildlife.

More recently, a wildlife component has been developed for SILVAH (see Thomasma and Cleveland 2019), and work is ongoing to develop compatibility for the SILVAH and the NED decision support tools (Twery 2019), including the NED wildlife module. All these developments require and are based on a knowledge of wildlife responses to forest management. A synthesis of that information specifically focused on avian responses follows.

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BIRDS AS FOREST DWELLERS

Why focus on birds? In part because a disproportionate share of the research on wildlife responses to forestry practices has focused on birds for numerous reasons, including:

- Birds are highly speciose compared to other terrestrial vertebrate orders. For example, Pennsylvania supports 414 bird species (including pass-through migrants and winter residents), compared to 66 mammal species and 77 species of reptile and amphibian (Steele et al. 2010, Wilson et al. 2012).
- Many birds are habitat specialists, particularly in forests (Stoleson and Larkin 2010). Avian community composition in forests varies with forest structure (Culbert et al. 2013, Niemi and Hanowski 1984), and structure can change drastically with forest management. Birds' ability to fly enables them to leave an area should habitat conditions deteriorate, making them excellent monitors of habitat quality and ecosystem health (Canterbury et al. 2000).
- Because most breeding birds advertise and maintain their territories by song, nonintrusive methods can easily be used to survey these species (Bibby et al. 1992).

Birds also enjoy a large constituency among humans; bird-watching has become the largest and fastest-growing outdoor recreational activity in the United States (Carver 2013). That fact, coupled with birds' ability to be surveyed nonintrusively by song, has resulted in several major citizen-science programs for monitoring bird populations at the regional, national, and international scales, such as the North American Breeding Bird Survey (BBS) (Canterbury et al. 2000). We therefore understand bird population dynamics better than those of any other taxon.

Results from the BBS have shown that populations of many bird species have declined since the program's inception in 1966; in that time, 23 percent of the species of eastern forests have shown significant declines (Rosenberg et al. 2016). These include many of our most characteristic and widespread forest birds, such as the wood thrush (*Hylocichla mustelina*), cerulean warbler (*Setophaga cerulea*), worm-eating warbler (*Helmitheros vermivora*), and black-billed cuckoo (*Coccyzus erythrophthalmus*). More than half of these forest birds are nearctic-neotropical migrants that move seasonally from breeding areas in the United States and Canada to wintering areas in the Caribbean, Central America, and South America. These annual movements constrain the time they can spend on their breeding grounds and consequently their resiliency to environmental changes relative to nonmigrants (Faaborg et al. 2010).

These declines should be cause for general concern, because forest birds provide a wide range of ecosystem services (Şekercioğlu 2006, Whelan and Marquis 1995). From a forestry perspective, perhaps the most important service is pest control, particularly of herbivorous insects. Almost all forest birds (including hummingbirds) consume at least some insects in their diet, and most are wholly or primarily insectivores during the growing season. The biomass of leaf-eating insects consumed by birds, and their effects on plants, can be impressive (Mäntylä et al. 2011, Marquis and Whelan 1994).

Birds also provide additional ecosystem services, including:

- Seed dispersal. Birds function as the primary seed dispersal agents for many plants (Howe and Smallwood 1982, Willson 1986).
- Ecosystem engineering in the form of cavity creation. Tree cavities are recognized as a "keystone resource" in forests globally and can be critical for a variety of wildlife species (Remm and Lõhmus 2011). Cavities can occur naturally through branch breakage or rot or can result from excavation by animals, primarily woodpeckers (Bednarz et al. 2004).

- Pollination. A variety of birds can be effective pollinators (Whelan et al. 2008), although in eastern North American forests only the ruby-throated hummingbird (*Archilochus colubris*) regularly serves this function.
- Energy transfer. Birds function as the primary carrion-eaters in terrestrial ecosystems globally (DeVault et al. 2016). In this role they provide an important, albeit underappreciated, energy transfer pathway (DeVault et al. 2003).

FOREST MANAGEMENT

Understanding how forest management affects forest birds can be critical for forest health and function and for the sustainability of bird populations. Numerous studies have examined the effects of various forestry practices on avian populations and to a lesser degree on nest success (Thompson et al. 1995, Sallabanks et al. 2000). Most such studies report on changes in abundance of birds overall or by species. Much less research has been conducted on demographic effects, such as nest success, fledgling success, fledgling or adult survival, or site fidelity, all of which may be better indicators than abundance of habitat quality (Van Horne 1983). Here I synthesize the results of research on the effects of the specific forest management practices prescribed by SILVAH. This is not meant to be an exhaustive review of the available literature. Studies included here are limited to those conducted in eastern deciduous or mixed forests and therefore relevant to SILVAH. They include research conducted by the USDA Forest Service's NRS-02 research work unit as well as studies published by others. See Stoleson et al. (2011), Ristau et al. (2011), and Trager et al. (2013) for a separate discussion of the effects of herbicides on nontarget species. For this review I have arranged management actions by decreasing intensity of their disturbance to forest structure.

Overstory Removal

The impacts to forest habitats are greatest with overstory removal, whether from true clearcutting or from the end point of a shelterwood sequence (Keenan and Kimmons 1993). Avian communities usually show a nearly complete turnover of species from forest interior species to early-successional specialists after overstory removal. The early-successional specialist species present vary with the time since harvest (DeGraaf et al. 1998, Schlossberg and King 2009, Yamasaki et al. 2014). Early-successional bird communities in overstory removal areas tend to include species that do not typically occur in shelterwoods or group selection openings (Gram et al. 2003, King and DeGraaf 2000). Some species prefer areas with very little ground cover immediately after harvest but leave as woody regeneration develops; others, such as the chestnut-sided warbler, begin to colonize once a dense understory of seedlings becomes established, typically 4 or more years postharvest. Avian abundance, species richness, and species density tend to peak 5-11 years postharvest, depending on forest type and latitude (Schlossberg and King 2009, Steffen 1985). Keller et al. (2003) found species richness and density in 6-year-old stands to be more than twice that of any mature stand sampled.

Mature forest birds begin to recolonize harvested areas 12-15 years postharvest, but most such species do not reappear until at least 25 years postharvest (Connor and Adkisson 1975, Keller et al. 2003). Between 25 years and 100 years after harvest, avian density and species richness increase slowly as tree growth, gap formation, and understory reinitiation create new foraging niches (Keller et al. 2003).

Shelterwood Cut

The term *shelterwood cut* in this chapter signifies the initial cut of a shelterwood regeneration sequence, which typically reduces stand density to 50-70 percent of its original canopy cover. Shelterwoods tend to support a full complement of late-successional birds but also support most local early-successional species (Annand and Thompson 1997, Goodale et al. 2009, King and DeGraaf 2000, Lanham et al. 2002, Newell and Rodewald 2012). Shelterwoods thus often have higher overall diversity and overall abundance than uncut controls or any other silvicultural treatment, although those differences decline with time since harvest (Duguid et al. 2016, Wang et al. 2006).

The effects of shelterwood cuts on birds tend to be guild-specific in response to changes in specific aspects of forest structure. Ground-foraging species tend to decline shortly after a shelterwood harvest because of the typically dense advance regeneration (Augenfeld et al. 2008, Gram et al. 2003, Newell and Rodewald 2012, Stoleson unpublished data[2]). Similarly, the removal of much of the midstory competing vegetation produces declines in midstory-nesting species (Newell and Rodewald 2012). In contrast, the dense understory that develops provides excellent habitat for shrub-nesting species of mature forests and early-successional species (Becker et al. 2011, King and DeGraaf 2000). Newall and Rodewald (2012) note an increase of more than 100 percent in the densities of shrub-nesting species. Response of understory nesters depends on successful regeneration and may be hampered or delayed by excessive deer browsing (Stoleson et al. 2011).

Of particular note is a suite of canopy songbirds that preferentially occupies broken or partially open canopies. This is presumably an adaptation to mature steady-state forests with active gap-phase dynamics (Bakermans and Rodewald 2009). Perhaps the best-known example of these gap-dependent species is the cerulean warbler, which has declined at a faster rate since 1966 than any other species of mature forest, 2.63 percent annually range-wide (Sauer et al. 2017). Other species that show similar habitat preferences include the yellow-throated vireo (*Vireo flavifrons*) and blue-gray gnatcatcher (*Polioptila caerulea*) (Newell and Rodewald 2012).

I conducted research on one example of the response of cerulean warblers to shelterwood harvests. In this study, avian abundance and nest success were monitored in three treatments in mixed-oak forests: shelterwood cut to 50 percent relative density following guidelines in Brose et al. (2008); an uncut buffer adjacent to the shelterwood (to assess edge effects), and an uncut control at least 250 meters from the nearest opening or harvest. All 4 replicate sites supported mature (85- to 110-year-old) second-growth mixed-oak forest on the Allegheny High Plateau in northwestern Pennsylvania. Shelterwoods had been cut 3-5 years earlier, such that understory regeneration was well advanced when the study began. Avian abundance and species diversity consistently peaked in shelterwood stands and was lowest in uncut controls. Several species occurred almost exclusively in shelterwood stands; these included a range of early-successional specialists such as chestnut-sided warbler (*Setophaga pensylvanica*) and indigo bunting (*Passerina cyanea*), shrub-nesting forest interior birds such as black-throated blue and hooded warblers (*Setophaga cerulescens*, *S. citrina*) and veery (*Catharus fuscescens*), as well as canopy gap specialists such as cerulean warbler and yellow-throated vireo. Nest success varied among nesting guilds but varied among treatments only for the shrub-nesting guild: shrub nests in shelterwoods were much more likely to fledge young than in either uncut treatment, probably because the understory density was much greater in shelterwoods. We found no nesting cerulean warblers or other canopy gap specialists in the uncut treatments, suggesting a real reliance on the presence of canopy gaps.

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Group Selection

Various studies have reported on the effects of group selection openings on birds, although the effects seem to vary greatly with the size and density of openings (Tozer et al. 2010). Most studies of group selection document short-term increases in some early-successional bird species (see Campbell et al. 2007, Jobes et al. 2004). However, Costello et al. (2000) show that group selection cuts (of < 0.8 acres) support only a small fraction of the early-successional bird species found in larger even-aged removal harvests (5 vs. 32 species). Annand and Thompson (1997), McDermott and Wood (2009), and Yamasaki et al. (2014) also demonstrate a reduced suite of early-successional species in group cuts compared to removal harvests. Species that are dependent upon larger gaps, such as the yellow-breasted chat (*Icteria virens*), tend to be absent from all group selection cuts. Tozer et al. (2010) report an increase in aerial foraging species, probably in response to opening of the canopy. Uncut portions of the stands containing group openings usually maintain their mature forest species (Annand and Thomson 1997, Campbell et al. 2007), although typically in reduced numbers. These forest-interior species often avoid the immediate area of the openings (Germaine et al. 1997). Fall migrants tend to use group openings more than adjacent uncut stands, perhaps because of the fruit resources produced by the early-successional vegetation that develops in openings (Kilgo et al. 1999).

In terms of demographic effects, Alterman et al. (2005) report no difference in nesting success rates between birds nesting within group openings and the same species nesting in nearby overgrown fields. Moorman et al. (2002) find no effect of proximity to group openings on nest success of shrub-nesting hooded warblers (*Setophaga citrina*). However, King et al. (1998) speculated that greater amounts of edge per unit area associated with group cuts may result in higher rates of nest predation than would be found in uncut stands, because nest predators hunt near edges.

Thinning and Single-Tree Selection Cutting

I consider these two treatments together, even though one is an intermediate treatment and the other is a final harvest option, because their impacts to forest structure are somewhat similar. In both, individual trees are removed, resulting in slightly opened canopies and a slight increase in the amount of light hitting the forest floor, potentially with a subsequent pulse of woody understory vegetation (Yanai et al. 1998).

Avian species richness and abundance in stands that are subject to thinning or single-tree selection tend to be intermediate between those found in unmanaged stands and those in shelterwood seed cuts (Annand and Thompson 1997, DeGraaf 1991, Freedman et al. 1981, Goodale et al. 2009). The magnitude of response by the avian community varies greatly with intensity of harvest (Holmes et al. 2004, Norris et al. 2011). Various researchers have noted declines in closed-canopy species such as ovenbird (*Seiurus aurocapillus*), especially for old forest specialists such as the brown creeper (*Certhia americana*) (Poulin et al. 2010). Overall abundance often declines as well (Hache et al. 2013, Heltzel and Leberg 2006, Holmes and Pitt 2007, Jobes et al. 2004, Robinson and Robinson 1999, but see Holmes et al. 2004).

Studies where canopy disturbance was sufficient to increase sunlight on the forest floor report corresponding increases in a few shrub-nesting species (Annand and Thompson 1997, Doyon et al. 2005, Haché et al. 2013, Heltzel and Leberg 2006, Jobes et al. 2004, Robinson and Robinson 1999). Although little studied, there is no published evidence that postfledgling survival is affected by these treatments relative to uncut controls (Moore et al. 20). For example, demographic parameters of ovenbirds do not differ between selection cuts and uncut controls up to 25 years postharvest (Leblanc et al. 2011).

Diameter Limit Cut/High Grade

Although possibly the most widespread timber management technique employed in eastern deciduous forests, especially on nonindustrial private land (Kenefic and Nyland 2005, Nyland 1992), diameter-limit cutting remains virtually unstudied in terms of its effects on wildlife. To date, a single published paper (Weakland et al. 2002) describes avian responses to light-intensity diameter-limit cutting. They report a higher total abundance of songbirds and higher nest survival in harvested stands than in controls, but few differences overall at their low level of harvest. The effects of heavier (and more typical) harvest levels remain unstudied.

Postbreeding Effects

Most of the information about the various timber management techniques refers specifically to responses of birds during their breeding season. In recent years a focus on full life cycle research has revealed that for many forest-breeding songbirds, habitat preferences are dynamic throughout their life cycle rather than static as once assumed (Faaborg et al. 2010, Zuckerberg et al. 2016). In particular, most late-successional breeders appear to shift to forest edges, riparian areas, and early-successional habitats once their young have fledged (Chandler et al. 2012, Cox et al. 2014, Rappole and Ballard 1987, Stoleson 2013). Regenerating clearcuts are shown to provide valuable postbreeding habitat for adults and fledglings of some late-successional species (Burke et al. 2017, Marshall et al. 2003, Pagen et al. 2000, Vitz and Rodewald 2006). Birds that move to regenerating cuts tend to be in significantly better physiological condition than those that remain in mature forest (Stoleson 2013), suggesting a clear adaptive strategy.

Fencing

Chollet et al. (2015), deCalesta (1994), Holt et al. (2013), McShea and Rappole (2000), Tymkiw et al. (2013), and other researchers have documented a correlation between deer abundance and bird communities. When white-tailed deer populations are abundant in an area, they often inhibit the development of diverse tree regeneration (Horsley et al. 2003). Consequently, high deer densities lead to reductions in understory bird species. When understory inventories indicate a lack of regeneration in a stand with a moderate to high deer impact level, SILVAH will usually prescribe a woven-wire fence to exclude deer to promote regeneration (see Vercauteren et al. 2006). Although fencing has no direct effect on birds, the resulting changes to understory vegetation can affect bird abundance and composition. Nuttle et al. (2011) followed up on the Allegheny Highlands deer enclosure study described by Horsley et al. (2003) and Royo and Stout (2019) by conducting bird surveys in the clearcut areas of that study 28 years after those cuts took place. By that time the stands contained dense pole-sized timber with almost no foliage at browsing level, and fences were down or compromised. Nuttle et al. (2011) show that higher ungulate densities during stand initiation caused significant reductions in tree species diversity, canopy foliage density, canopy insect density, and bird density in young forests.

CONSERVATION IMPLICATIONS

Overall, avian abundance and species richness peak several years after harvest in shelterwood cuts and overstory removals, then decline over time. Of course, not all species are of equal conservation concern, and abundance and species richness have little relevance to conservation value. Species and guilds vary in their level of conservation concern (Nuttle et al. 2003). Fully 45 percent of early-successional species have shown significant declines since 1966 based on BBS trends, in contrast to 23 percent of mature forest species and

19 percent of wetland obligate species (Dettmers 2003). In today's eastern deciduous forests, early-successional habitats are created primarily by timber harvests because many natural disturbance factors such as beavers and fire have been almost totally lost (DeGraaf and Yamasaki 2003, Trani et al. 2001). Overstory removals support a full suite of early-successional bird species, and shelterwoods nearly a full suite. Uneven-age treatments, such as group or single-tree selection, provide too little shrubby habitat to support more than a few early-successional species. Even-aged silviculture tends to allow for greater conservation of multiple guilds and suites of species across a landscape and is therefore preferable in most cases to uneven-age treatments, from a bird conservation perspective.

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The content of this paper reflects the views of the author, who is responsible for the facts and accuracy of the information presented herein.

WILDLIFE HABITAT ASSOCIATIONS IN SILVAH AND NED

Scott Thomasma and Helene Cleveland[1]

Insights for Managers

- **For several states in the northeastern and north-central United States, habitat assessment models have been developed that link wildlife species to the structural and compositional features of forests as determined in forest inventories.**
- **Four of these are included in the NED decision support system and in a stand-alone program called WHAM (Wildlife Habitat Assessment Matrices).**
- **Users of SILVAH and NED can access the models in NED and produce lists of species whose habitat needs are met based on the data collected.**
- **The Pennsylvania habitat assessment model originated in the 1990s and has been recently updated through cooperation with a committee of wildlife scientists and several of the Commonwealth's Biological Survey technical committees.**

INTRODUCTION

Foresters and wildlife managers have long known that forest management activities have impacts on wildlife communities (see Smith 1962). Research has also shown that private landowners often cite provision of wildlife habitat as one of their main reasons for owning forest land (Hodge 1996, Jones et al. 1995, Kluender et al. 1999). Direct census of wildlife populations is challenging and expensive, and until the late 1980s, publications developed to provide information on how forest management activities can benefit wildlife tended to focus on single species, especially game species, and how to manage their habitats, such as deer wintering areas in northern regions (see Berner and Gysel 1969, Boer 1978, Larson et al. 1978).

In 1969 a breakthrough occurred as a result of an effort led by Jack Ward Thomas, who was a USDA Forest Service wildlife biologist and later Chief of the Forest Service. The breakthrough was the first report that listed wildlife habitat associations for hundreds of species in a specific region: the Blue Mountains of Oregon and Washington. The report contained various matrices that showed what each species' habitat needs were, such as bogs, snags, or standing water. The authors believed that "Habitat, therefore, is the key to organizing knowledge about wildlife so it can be used in forest management" (Thomas 1979).

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Table 1.—Vegetative and physical structural features

Layer	Feature
Ground (0–2 feet)	Amount of dead and downed logs
	Percent cover of rocks, forest litter, and vegetation
Shrub (2–10 feet)	Percent cover of vegetation
	Type of shrub (deciduous, coniferous, ericaceous)
Midstory (10–30 feet)	Percent cover and type (deciduous and coniferous)
	Snags (dead trees)
	Trees with cavities (live or dead)
Overstory (>30 feet)	Same as midstory
Within-stand	High exposed perches—live or dead overstory trees that clearly tower above the main canopy
	Low exposed perches—those in the shrub layer such as fences, downed tops, or snags shorter than 10 feet
	Water sources—vernal ponds, permanent ponds, seeps, and perennial streams
	Subterranean habitat—friable soil (soil that can be burrowed into), rock piles, rock crevices leading below the frost line, and caves
	Mast species—soft or hard mast producers

DEVELOPMENT OF HABITAT ASSESSMENT MODELS FOR EASTERN FORESTS INCLUDING PENNSYLVANIA

For northeastern foresters, Richard DeGraaf and his colleagues began work to produce a similar tool (DeGraaf et al. 1992, DeGraaf and Rudis 1986). DeGraaf et al. (1992) compiled habitat information for more than 300 species of amphibians, reptiles, birds, and mammals. The report contained matrices that showed the forest type, size-class, and the horizontal and vertical structural features (Table 1), such as cavities or ground cover, required by each species.

DeGraaf et al. (1992) inspired much additional work. Some of that is described in Twery (2019) as early products of the NED development team (Thomasma et al. 1998, Twery et al. 2012). Northrop (2009) followed this model in Maryland, and Thomasma et al. (2007) followed it in Michigan. In Pennsylvania in the early 1990s, Jim Finley of Pennsylvania State University and student Helene Cleveland carried these ideas one step further. Their work was intended to modify a traditional silvicultural inventory to also acquire data on structural features important to wildlife and use data from such an inventory to determine which wildlife species had potential habitat in a stand. Their work involved three steps:

1. Review and adapt or acquire habitat data for Pennsylvania.

   Because the DeGraaf et al. (1992) publication was for New England, we needed to review that information to determine which species inhabited Pennsylvania and whether their habitat needs were different. To acquire habitat data, we sent a series of questionnaires to the Pennsylvania Biological Survey technical committee members, to biologists in the Pennsylvania Game Commission, and to experts in the mid-Atlantic region asking for their help in reviewing and revising the New England habitat data and acquiring data on species inhabiting Pennsylvania but not New England. The result was habitat data for 227 Pennsylvania species.

2. Determine how to measure habitat structural features quickly and accurately in a way that would complement a silvicultural inventory.

   To modify a silvicultural inventory to measure habitat structural features, we researched various methods to determine percent cover, dead and downed woody debris, cavities, etc. After reviewing texts of sampling methods (Brower and Zar 1977, Brown 1954, Schreuder et al. 1993) and conducting inventories at the Penn State Stewardship Forest (Harvey 1994), it became apparent that some structural features would be expensive to measure accurately. These features appear in such small quantities or are so scattered in the stand that they would require an excessive number of plots to be statistically accurate. However, these features are important habitat components. The compromise, in most situations, is to note their presence if they occur within a stand. These within-stand features (Table 1) include water sources (vernal or permanent ponds, perennial streams, or seeps); subterranean habitats (friable soil, rock piles, rock crevices, or caves); and soft or hard mast-producing species. For the other features we investigated various percent cover measurements, line transects for dead and downed logs, relative density, and basal area measurements.

3. Develop an easy way to use the computer capabilities of the early 1990s to manage the data to provide a list of species that potentially had habitat without going line by line through the matrices for hundreds of species.

The result was the Habitat Assessment Model or HAM (Cleveland and Finley 1998, Harvey 1994), which contained an inventory process to produce stand-level data that could be used in a manual format (using groups of species) or a computer format to determine a list of potential species' habitats. Foresters could also predict the changes an activity would make to the stand, for example, changes caused by a thinning or shelterwood. Foresters could run the predicted post-treatment data again and get a list of species' habitats that would be in the postactivity stand. The second list would provide an idea of which species' habitat would be lost, added, or unchanged to aid in decisionmaking.

For the original computer format and for HAM's inclusion in the NED program, every species in HAM has a rule that is compared to inventory data. An example using the winter wren (Table 2) shows it uses only three forest types and only the large sawtimber size-class. It also needs dead and downed wood, either deciduous or coniferous shrubs, and live or dead cavity trees. So if a stand with these features is entered in NED, the program will list winter wren as having potential habitat in the stand.

As with any program or model, habitat assessment models have important limitations:

- Information about structural features for some species is limited, and assessment outcomes should be treated as hypotheses.
- Inventory data are averages and do not reflect patchiness that a species may be using.
- The inventory is for a single stand—it does not consider nearby landscape variables that may influence site use by some species.
- Forest types were based on DeGraaf et al. (1992) and needed to be expanded to fit Pennsylvania conditions.

Table 2.—Computer rule showing habitat requirements for winter wren

WHITE PINE or EASTERN HEMLOCK or WHITE PINE/RED OAK/RED MAPLE
And LARGE SAWTIMBER
And 50 cu ft DEAD & DOWN
And DECIDUOUS SHRUBS (> 20%) 'or' CONIFEROUS SHRUBS (> 20%)
And DEAD CAVITY TREES or LIVE CAVITY TREES

RECENT UPDATES AND IMPROVEMENTS

As more wildlife managers became aware of the SILVAH-Oak guidelines for sustaining oak in oak forests and participated in the associated training sessions (see Brose 2019), interest in strengthening the wildlife relevance of SILVAH grew. In September 2012 the SILVAH team held a workshop for interested wildlife managers. The goal was to brainstorm ways to strengthen the wildlife aspects of SILVAH and to introduce Pennsylvania wildlife managers to NED and its capabilities. The result of the meeting was a sustained effort that included three main thrusts:

1. Update the Pennsylvania habitat assessment data.
2. Develop a stand-alone tool that is based on all the models currently in NED to explore wildlife habitat relationships in forest.
3. Strengthen the links between SILVAH and NED so SILVAH users would be able to use the same data to access recommendations for regenerating and managing oak forests and the wildlife habitat assessment capabilities of NED.

UPDATING PENNSYLVANIA WILDLIFE HABITAT RELATIONSHIPS

To minimize the limitations and take advantage of habitat research since 1994, the original HAM data (Harvey 1994) were compared with habitat data from the 2005 and 2015 Pennsylvania Wildlife Action Plan and habitat data on other refereed websites (such as Birds of North America at Cornell University). Members of the Pennsylvania Biological Survey technical committees and other experts are reviewing and revising the resulting data. Their revisions will be incorporated into NED. At the same time, a built-in update process has been added to the software to allow experts to provide suggested changes at any time. The SILVAH/NED wildlife team will then review and incorporate these suggestions.

The Pennsylvania Game Commission has provided up-to-date species ranges by county (the original model had ranges by physiographic provinces) and other State of Pennsylvania databases.

The updated Pennsylvania habitat assessment model was also compared to MDWILD (Northrop 2009), to habitat associations in the 2015 Pennsylvania Wildlife Action Plan, and to U.S. Forest Service Forest Inventory and Analysis forest types to expand HAM forest types to include oak-hickory, oak-pine, and hard pine (pitch pine, Virginia pine, etc.). Release of the newest updates is awaiting final review by the Forest Service biologists.

Acquiring data on species' habitat structural features is difficult and complicated. However, as stated in the 2005 Pennsylvania Comprehensive Wildlife Conservation Strategy (which became the Wildlife Action Plan):

> "Clearly defining species-habitat associations is somewhat complicated … Though complicated and incomplete, it is nevertheless vitally important to attempt to associate species with their key habitats to begin formulating conservation goals and objectives" (PGC-PFBC 2005).

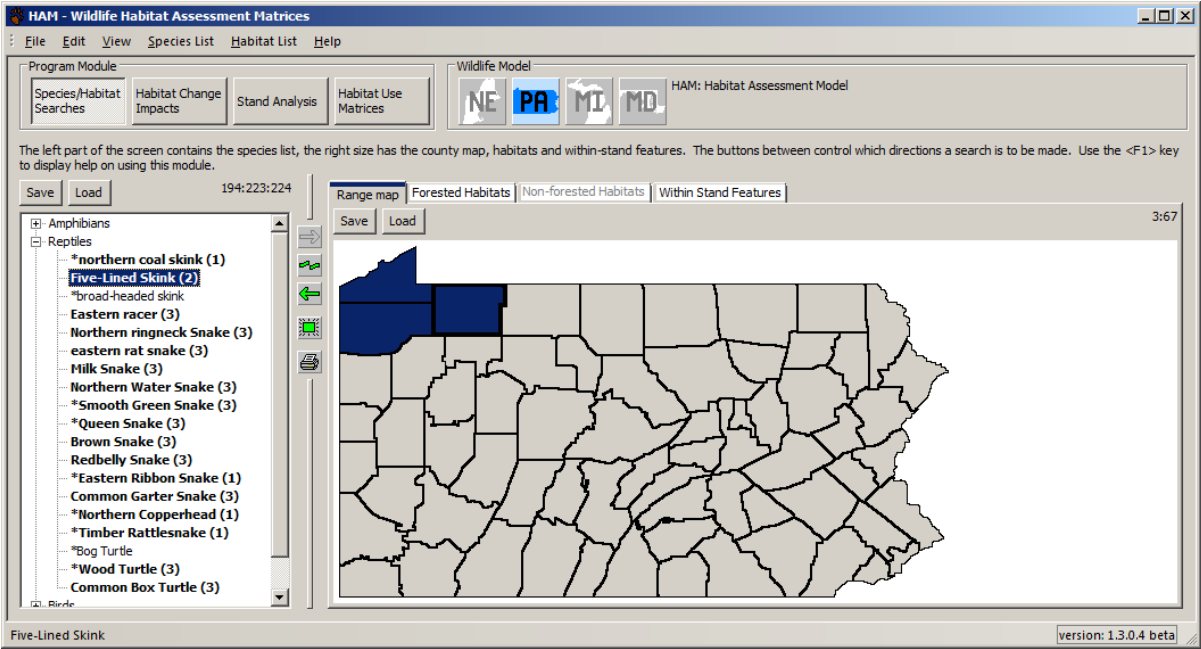

Figure 1.—Species list (species in bold) for three northwestern Pennsylvania counties.

DEVELOPMENT OF WHAM

The updated models for Pennsylvania, as well as those for Michigan (MIWILD; Thomasma et al. 2007), Maryland (MDWILD; Northrop 2009), and the model based on the DeGraaf et al. (1992) data (NEWILD; Thomasma et al. 1998), are included in a new computer program called the Wildlife Habitat Assessment Matrices (WHAM, a stand-alone program that contains all the data from the four habitat models, including species ranges, forest types, size-classes, structural features, and, for some models, nonforest structural features such as agricultural land. It relies on specific but qualitative or presence/absence information about habitat attributes rather than inventory data and can provide information at several scales of space and time.

WHAM can provide species lists by county or several counties. Figure 1 shows which species inhabit three counties in northwestern Pennsylvania. The numbers after the species names indicate the number of counties of the three in which it was found. A search can also be done in reverse; that is, by clicking on one or several species the user can find which county or counties they inhabit. Similar searches can be done for forest types, size-classes, and within-stand features and any other data in the matrices.

WHAM can also help you understand habitat change. Figure 2 shows the results of a stand growing into the next size-class. The "pre" condition acreage was northern hardwoods 20 acres, red maple (*Acer rubrum*) 30 acres, and balsam fir (*Abies balsamea*) 50 acres, all in the seedling size-class. The "post" conditions are the same acreages for the same forest types, but at the sapling-pole size-class because of growth. The species list on the right shows habitat gains and losses. The red cells are losses, the green are gains. The Blackburnian warbler (*Setophaga fusca*) gains 50 acres, and the chestnut-sided warbler (*Setophaga pensylvanica*) loses 50 acres. The values in the "pre" and "post" conditions could also represent changes caused by forest management actions; the results would show the difference in wildlife habitat. This type of lookup has also been used to evaluate land swaps where an agency was contemplating exchanging ownership of one area for another.

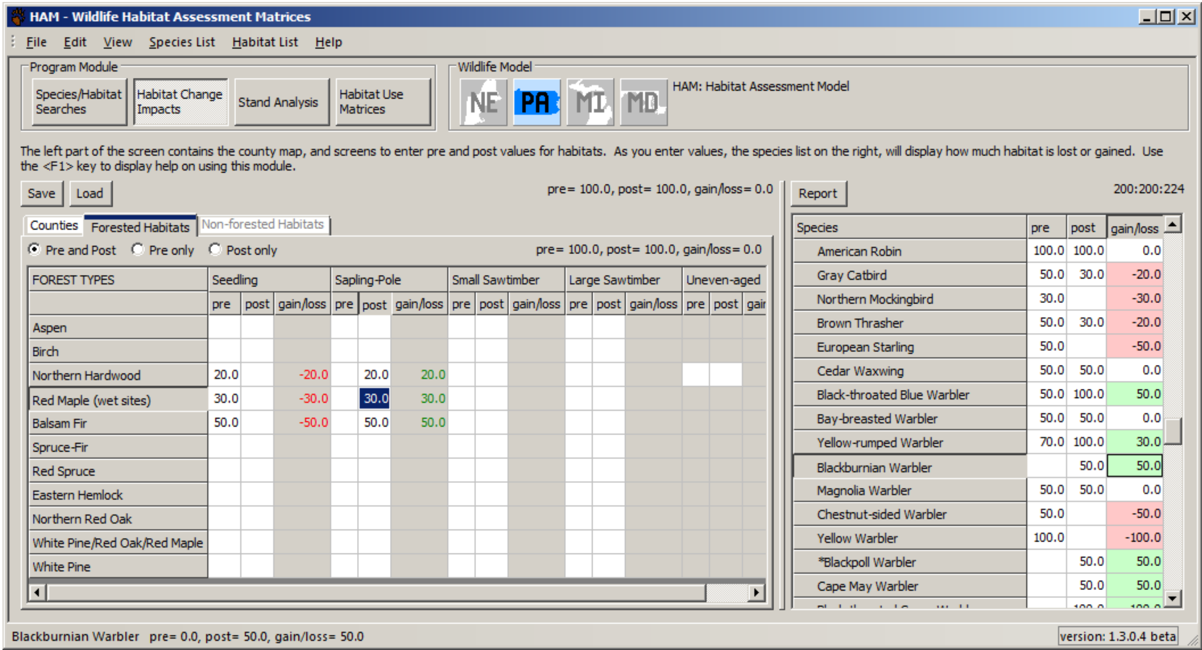

Figure 2.—Habitat change caused by trees growing into next size-class.

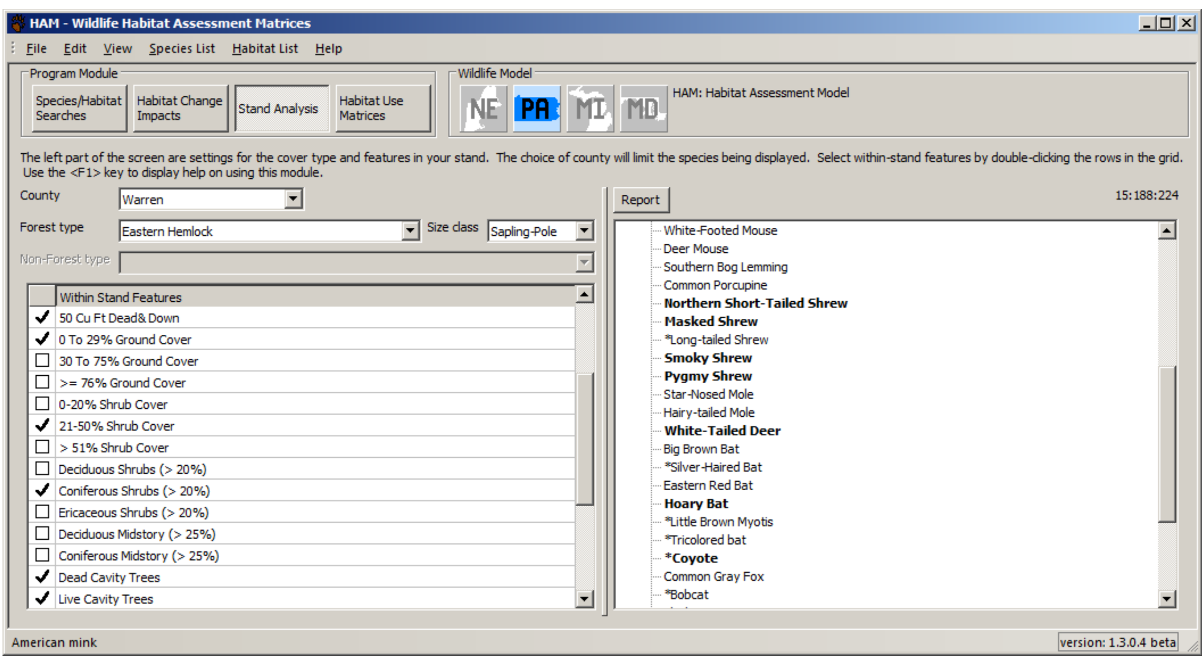

Figure 3.—Species list for an eastern hemlock sapling-pole stand in Warren County, PA.

Figure 3 shows the results of a single stand evaluation. In this example, the stand is located in Warren County (which limits the species list to the right on the figure). It's an eastern hemlock (*Tsuga canadensis*) sapling/pole stand, and a few within-stand attributes have been selected including dead/downed and forest litter. The species list on the right has the wildlife species (in bold) for which the stand meets the rules. The evaluation is conducted using the species rules and finding species whose habitat attributes are found in the stand. For example, the masked shrew (*Sorex cinereus*) is boldface on that list. The deer mouse (*Peromyscus* spp.) and other species are not included, because some feature they need does not exist on the stand.

Wildlife Habitat Report: Habitat Assessment Model (HAM

Deer Mouse (*Peromyscus maniculatus*)

The stand does not provide suitable habitat.

Rule:

```
Any forest type
Any size class
'50 cu ft DEAD& DOWN'
and 'SOFT MAST' or 'HARD MAST'
```

Habitats and features used in species rule:

Stand feature	value
County	Warren
Land Cover Type	EASTERN HEMLOCK (SAPLING-POLE)
50 cu ft DEAD& DOWN	present
SOFT MAST	absent
HARD MAST	absent

County List:

Adams, Allegheny, Armstrong, Beaver, Bedford, Berks, Blair, Bradford, Butler, Cambria, Cameron, Carbon, Centre, Clarion, Clearfield, Clinton, Columbia, Crawford, Cumberland, Dauphin, Elk, Erie, Fayette, Forest, Franklin, Fulton, Greene, Huntingdon, Indiana, Jefferson, Juniata, Lancaster, Lawrence, Lebanon, Lehigh, Luzerne, Lycoming, McKean, Mercer, Mifflin, Montour, Northumberland, Perry, Potter, Schuylkill, Snyder, Somerset, Sullivan, Susquehanna, Tioga, Union, Venango, **Warren**, Washington, Westmoreland, Wyoming, York

Figure 4.—Habitat report showing the features needed by the deer mouse.

The user can click on "deer mouse" to see a wildlife report (Fig. 4) that shows the features needed by the deer mouse and comparing them with the attributes of the stand data that were input. For the deer mouse, neither soft nor hard mast was listed as a stand attribute. The program shows how the species list changes when within-stand attributes are added to or removed from the stand. In this example, if the user goes back and checks off one of the mast types (hard or soft), the deer mouse will be included.

Strengthening the SILVAH/NED Connection

We use the same wildlife rules in habitat evaluation in NED (Twery et al. 2011, 2012). NED is a forest ecosystem management decision support system (https://www.nrs.fs.fed.us/tools/ned/products/ned3/). It contains a family of software products that are intended to help resource managers develop goals, assess current and future conditions, and produce sustainable management plans for forest properties. There is an easy way to import SILVAH (https://www.nrs.fs.fed.us/tools/silvah/) data into NED, and it was decided not to duplicate the same wildlife analysis in both programs. NEWILD, MIWILD, HAM, or MDWILD are used for wildlife analysis. NED has the advantage of being able to input or import inventory data (e.g., SILVAH data) from several stands and evaluate how the stands meet species' needs using the same rules as WHAM.

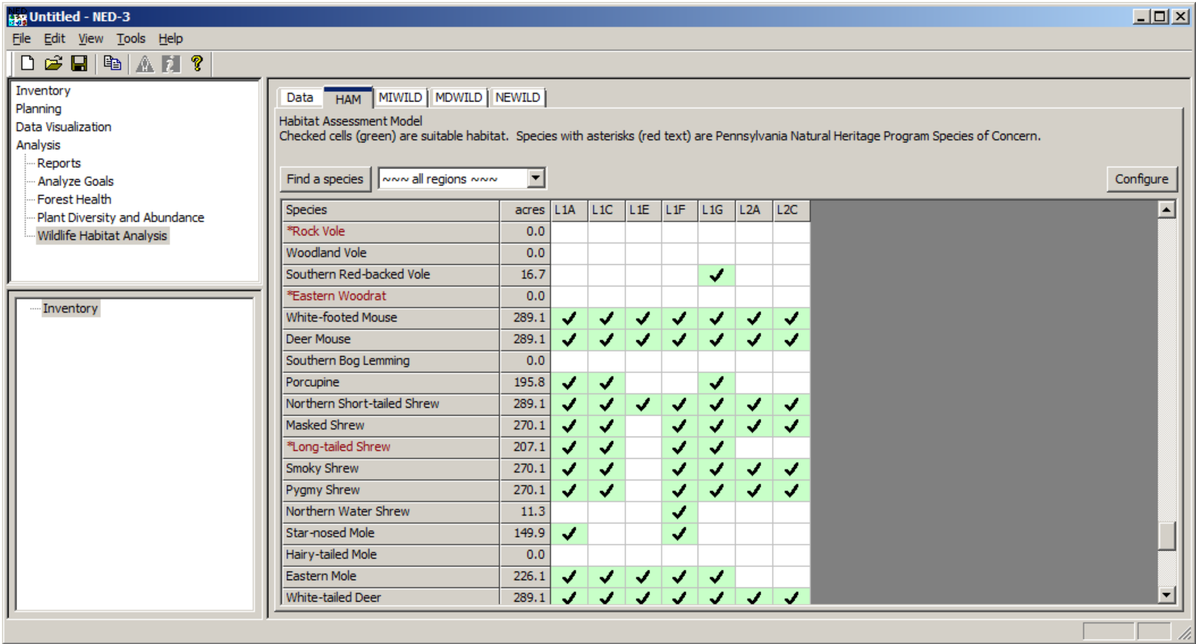

Figure 5.—Wildlife list for multiple stands in NED.

Figure 5 shows the species that find habitat in various stands in a single property (highlighted with a green arrow). A click on any green arrow (or empty cell) brings up a short description of the habitat requirements that were evaluated so the user can understand the model. A user can run this model on stand conditions before and after a silvicultural treatment to understand possible habitat changes.

Clicking on the block for the southern red-backed vole in stand L1G brings up the report in Figure 6. The report shows how the stand attributes meet the species rule. To understand why the southern red-backed vole (*Myodes gapperi*) does not have habitat in stand L1F, the user must view the report by clicking on the box and the data from the inventory. The report shows that the stand lacks sufficient shrub cover (Fig. 7). The stand contains only 3.8 percent shrub cover, when it needs a minimum of 21 percent shrub cover. Therefore, stand L1F does not provide all the necessary habitat structural features for the vole.

The NED and WHAM programs quickly allow users to determine which species potentially have habitat in the stand or stands. By evaluating which structural feature may be limiting, the manager can plan to add or create the feature in the stand; for example, piling rocks for basking sites along skid roads, leaving cavity trees, or creating vernal ponds. Paraphrasing one of the HAM reviewers, “no one is going to manage for shrews or voles, but they are extremely important to higher predators and it’s good to show managers what structural features are important to them so they can plan accordingly.”

Wildlife Habitat Report: Habitat Assessment Model (HAM)

Stand: L1G

Southern Red-backed Vole (*Myodes gapperi*)

The stand is suitable habitat, the following conditions are met: Any forest type Any size class '50 cu ft DEAD& DOWN' and '21-50% SHRUB COVER' and '30% FOREST LITTER'

Species Rule:

```
Any forest type
Any size class
'50 cu ft DEAD& DOWN'
and '21-50% SHRUB COVER' or '> 51% SHRUB COVER'
and '30% FOREST LITTER'
```

Habitats and features used in species rule:

HAM feature	NED variable	value
Habitat Type	HAM Forest Type NED Forest Type	WHITE PINE oak southern pine
Size Class	Size class	large sawtimber
50 cu ft DEAD& DOWN	Coarse Woody Debris	178.3 (cu.ft./ac.)
21-50% SHRUB COVER	Shrub layer cover	28.3 (% cover)
30% FOREST LITTER	Leaf litter cover	80.0 (% cover)
> 51% SHRUB COVER	Shrub layer cover	28.3 (% cover)

Figure 6.—Report showing how stand L1G attributes meet the habitat rule for the southern red-backed vole.

Wildlife Habitat Report: Habitat Assessment Model (HAM)

Stand: L1F

Southern Red-backed Vole (*Myodes gapperi*)

The stand does not provide suitable habitat.

Species Rule:

```
Any forest type
Any size class
'50 cu ft DEAD& DOWN'
and '21-50% SHRUB COVER' or '> 51% SHRUB COVER'
and '30% FOREST LITTER'
```

Habitats and features used in species rule:

HAM feature	NED variable	value
Habitat Type	HAM Forest Type NED Forest Type	NORTHERN HARDWOOD Appalachian hardwoods
Size Class	Size class	small sawtimber
50 cu ft DEAD& DOWN	Coarse Woody Debris	90.8 (cu.ft./ac.)
21-50% SHRUB COVER	Shrub layer cover	3.8 (% cover)
30% FOREST LITTER	Leaf litter cover	60.0 (% cover)
> 51% SHRUB COVER	Shrub layer cover	3.8 (% cover)

Figure 7.—Report showing how stand L1F attributes do not meet the habitat rule for the southern red-backed vole.

CONCLUSION

Since the early 1990s, developments in the NED family of decision support tools included increasingly powerful ways to understand the relationships between forest attributes, forest management, and the known habitat needs of hundreds of wildlife species. The result is a family of computer programs, including NED, WHAM, and, indirectly, SILVAH, which provide powerful support for managers who want to consider wildlife habitat needs and consequences of management actions.

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THE CARBON CONSEQUENCES OF THINNING ALLEGHENY HARDWOODS: LESSONS LEARNED FROM A STUDY DESIGNED TO INFORM SILVAH DEVELOPMENT

Coeli Hoover[1]

Insights for Managers

- Consider thinning methods carefully. Methods that substantially change stand structure may significantly slow stand growth or stimulate understory growth, both of which can have negative impacts on volume and carbon.
- Understand the factors, such as site index and elevation, which may affect the results of thinning treatments. At lower productivity sites thinning may not substantially increase stand growth or carbon storage.
- Carefully consider the two components of carbon sequestration: standing carbon stock and the rate of change in carbon stocks. Management objectives may determine whether one is somewhat more important than the other.
- The time frame is also important: the same treatment may have different short-term and long-term outcomes. The time frame of the analysis depends on management objectives. For example, stands thinned according to best practice will have a higher rate of carbon accumulation for about 10 years post-thinning, though after 30 years thinned and unthinned stands are likely to contain about the same amount of carbon.
- Plan at a landscape level. Young stands have a high rate of carbon accumulation but a very low standing carbon stock; older stands have a high standing stock but a very low rate (or perhaps a steady state) of carbon accumulation. Maintain a mix of age classes across the landscape to optimize the balance between the two. Maintain a mix of species across the landscape to ensure a hedge against species-specific disturbances.
- Carbon management objectives are generally compatible with sustainable timber production and wildlife management; all benefit from a mix of species and age classes across the landscape.
- Sustainable forestry practices are good carbon forestry practices.

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INTRODUCTION

About 50 years ago, scientists and managers collaborated in an effort that would evolve into the Silviculture of Allegheny Hardwoods (SILVAH) system. Stout and Brose (2014) summarize this unusual story. SILVAH includes components that range from inventory methods to training sessions to management prescriptions, all of which were designed from the ground up and driven by the needs of managers working in Allegheny hardwood forests. Today, SILVAH has been expanded to support oak forest types.

Decision support systems often summarize expert knowledge and synthesize guidelines; scientists experimented with many of SILVAH's underlying principles, which managers tested to develop this system. A good example is the set of thinning guidelines. A multiple-block replicated thinning study was established in 1975 to determine the thinning prescription that would provide the desired results for Allegheny hardwood stands. The study examined two components:

- Thinning intensity, where plots were thinned to a range of relative density levels.
- Thinning type, where plots were thinned to the same relative density using different methods (Marquis and Ernst 1991). This study includes the 10-year results. Many blocks of the thinning study continue to be inventoried at 5-year intervals, and some have been retreated over time.

Because improved forest management is a recognized approach in the carbon credit market for increasing carbon storage in forests, Hoover and Stout (2007) used the inventory data from the block where different thinning methods altered stand structure to assess the carbon consequences of various thinning techniques. At that time, the stands had been treated twice; the most recent data inventory was conducted in 2000. They found that the thinning method applied had important effects on carbon storage and timber production. Stands that had been thinned from above contained significantly less carbon and merchantable volume than those thinned from below or left unthinned (rates of change also varied). Since then, the stands have been treated a third time. This chapter discusses the impact of the thinning methods on stand structure, merchantable volume, and carbon stocks and yields after three treatments and 37 years.

MATERIALS AND METHODS

Thinning Treatments

The study was established in 1975 on the Kane Experimental Forest in northwestern Pennsylvania. At this time, the forest was even-aged pole timber-size Allegheny hardwoods, dominated by black cherry (*Prunus serotina*), sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), and red maple (*Acer rubrum*). All stands were slightly more than 50 years old, having arisen after the nearly complete clearcutting of the existing old-growth forest in 1922-1923. Each plot is 2 acres; the interior 0.6 acres is designated as the measurement area, and the remaining 1.4 acres serve as a buffer. The entire 2-acre plot was treated. All treated plots were thinned to 60-70 percent relative density. Three thinning methods were compared for this analysis:

- Control, with no thinning (n = 2 plots).
- Thin from above: Commercial thinning by diameter, starting at the largest diameter and working down until the density target was met (n = 3 plots).

- Thin from middle: Commercial thinning; no noncommercial saplings were cut. Starting at the lowest merchantable diameter class and working upward until density target is met (n = 3 plots).
- Thin from below: Noncommercial thinning, starting at the lowest diameter class and working upward until density target is reached (n = 3 plots).

All plots were tallied before treatment (all stems 1 inch diameter at breast height and higher); following the first thinning, the plots were reinventoried and all stems larger than 1 inch diameter at breast height were marked with a numbered tag for subsequent measurements. Plots were tallied approximately every 5 years. A second round of treatments was applied in 1990 and a third in 2011. The most recent inventory was taken in 2012. For additional details on the implementation of the treatments, see Marquis and Ernst (1991).

DATA ANALYSIS

We used SILVAH 7 (Thomasma and Stout 2017) to process inventory and to calculate basal area (BA), trees per acre (TPA), median merchantable diameter, and net board foot volume (BF; International ¼ inch Rule). We used the species and diameter data from the inventory records to calculate aboveground and belowground biomass according to Jenkins et al. (2003). Live tree biomass remained in the live tree carbon pool. Biomass in trees recorded as dead was transferred to the dead wood pool, and a fixed decomposition rate was applied; similarly, when a treatment was applied the biomass in the tops of the trees was allocated to the slash category and a decomposition coefficient was applied (following Birdsey 1996). We used the coefficients from Smith et al. (2006) to include the biomass in the cut stems in the wood products pool; this pool is the sum of carbon in products in use and discarded in landfills. The carbon in harvested wood products changes over time as more products become discarded and decompose, and only a proportion of harvested carbon initially is included in products, because waste occurs during processing and may be burned or discarded. For all pools, carbon is calculated as 50 percent of dry biomass weight. Differences were tested by one-way analysis of variance after checking assumptions of normality and equal variance; multiple pairwise comparisons were conducted using the Holm-Sidak test.

RESULTS

Stand Characteristics

Before treatment, all plots had similar BA, TPA, medial merchantable diameter, and net volume (Table 1). By 2000, 10 years after the second thinning treatment, BA, merchantable diameter, and net volume were lowest in the thin from above treatment (81 ft^2/acre, 8.1 inches, and 161 BF/acre, respectively). In contrast, the thin from below treatment had the highest values for these variables (103 ft^2/acre, 16.4 inches, and 9319 BF/acre), although values were similar for the control plots. At the most recent measurement, 2 years after the third treatment, the number of trees does not differ significantly between treatments, although BA, merchantable diameter, and net volume are significantly lower in the plots thinned from above than in any other treatment or the control plots. Almost no merchantable volume remains in the plots thinned from above, and merchantable diameter is less than half that in the other treatments (Table 1).

Table 1.—Mean and standard error (in parentheses) of selected stand attributes. In 2000, stands were 10 years post-treatment after the second thinning. In 2012, the most recent measurement, stands were 2 years post-treatment after the third thinning.

	Basal area ($feet^2$/acre)	Trees/acre	Merch. dia.[a] (inches)	Net BF/acre[b]
Pretreatment				
Below	131 (6.1)	908 (34.3)	11.5 (0.31)	4065 (609)
Middle	148 (4.9)	929 (42.9)	11.0 (0.55)	4373 (577)
Above	131 (6.1)	770 (42.9)	10.9 (0.31)	3634 (735)
Control	128 (8.4)	824 (64.1)	10.6 (0.05)	3314 (135)
After Cut 1975				
Below	96 (1.7)	1840 (165.7)	11.9 (0.38)	3791 (571)
Middle	80 (7.4)	1279 (172.1)	11.3 (0.41)	2145 (422)
Above	65 (3.1)	1704 (91.5)	8.5 (0.56)	393 (273)
Control	122 (7.0)	1009 (119)	10.7 (0.05)	2985 (18)
2000				
Below	130 (9.2)	1271 (115.8)	16.4 (0.27)	9319 (1273)
Middle	107 (7.4)	812 (145.4)	14.8 (0.17)	5802 (1115)
Above	81 (1.4)	1081 (80.5)	8.1 (0.32)	161 (122)
Control	120 (11.5)	494 (57.5)	14.9 (0.00)	7045 (1280)
After Cut 2012				
Below	129 (8.1)	363 (64.1)	18.0 (0.67)	11281 (1646)
Middle	106 (10.0)	522 (40.9)	17.2 (0.27)	7185 (1234)
Above	67 (6.7)	576 (58.2)	7.5 (0.33)	24 (24)
Control	120 (0.05)	529 (36.0)	15.8 (0.35)	6897 (549)

[a] Medial merchantable diameter
[b] Net board feet (BF), International ¼ inch Rule

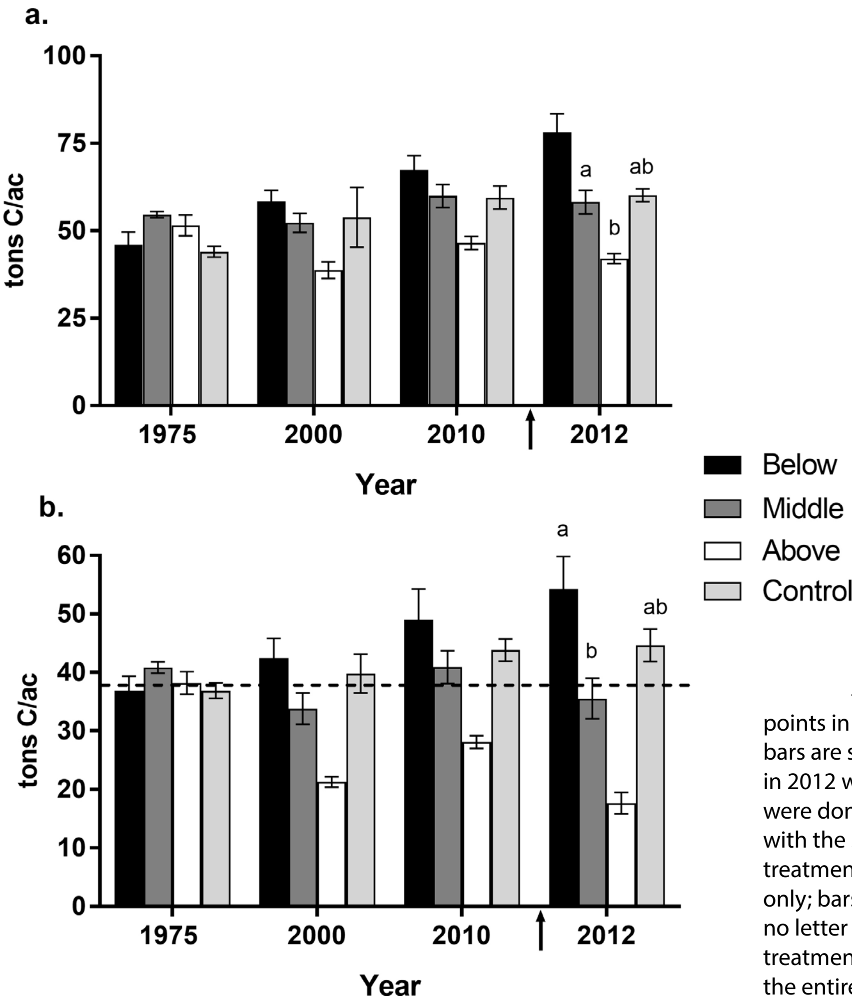
Table 2.—Mean carbon stocks (tons C/acre) by pool for each treatment in 2012, after three thinnings. Values in parenthesis indicate stock before first treatment in 1975.

	Below	Middle	Above	Control
Live tree [a]	54.2 (37)	35.5 (41)	17.7 (38)	44.6 (37)
Live root	10.2	6.8	3.4	8.5
Dead wood	7.2	5.9	8.9	7.0
Slash	3.6	4.6	4.3	0
Products	2.9	5.4	7.8	0
Total	78.1	58.2	42.0	60.1

[a] Aboveground
Does not include shrubs

Carbon Stocks and Stock Changes

Before the stands were thinned, all plots had similar amounts of carbon in live aboveground tree biomass (range: 37-41 tons/acre). By 2012, both the amount of carbon and the distribution among pools varied by treatment (Table 2); the lowest amount of live tree carbon and the largest amount of carbon in wood products appeared in the thin from above treatment. Conversely, average live tree carbon stocks are highest in the plots thinned from below. The non-live carbon pools are similar across treatments (except for slash and products carbon in the control plots, which have zero values).



—Carbon stock, in tons/acre, by thinning treatment at selected points in time. Arrow indicates time of most recent treatment. Error bars are standard error of the mean. Differences between carbon stocks in 2012 were compared with analysis of variance (no comparisons were done for other years). Figure 1a: All carbon pools included; bars with the same letter do not differ significantly at p = 0.05; otherwise, treatments differ significantly. Figure 1b: Aboveground live tree carbon only; bars with the same letter do not differ significantly at p = 0.05. If no letter is present, that treatment differs significantly from the other treatments. Dashed line indicates average live tree carbon stock over the entire study before the first thinning treatment.

For overall carbon stocks examined at points through time, the pattern remains similar (Fig. 1a): the differences that were apparent in 2000, 10 years after the second treatment, remain in 2012, 2 years after the third thinning. Average carbon stocks (for all estimated pools) are significantly higher in the plots thinned from below, and plots thinned from the middle contain significantly more carbon than those thinned from above. However, the total carbon stocks in the stands thinned from above and from the middle do not differ from those in unthinned control plots (n = 3 for the treated plots; n = 2 for controls). An upward trend in total standing carbon stocks is apparent over time in all but the plots thinned from above, which stored less carbon in 2012 than in 1975. Looking at just the carbon stored in the aboveground portion of living trees, the differences between thinning approaches become even more apparent (Fig. 1b); the dashed line indicates the experiment-wide pretreatment average live tree carbon stock. By 2012 the stands thinned from above have far less carbon in live biomass than at the beginning of the study; significantly less than the other treatments or the unthinned controls. More live tree carbon is present in the thin from below treatment, this difference is significant compared to the thin from the middle, though not from the untreated controls.

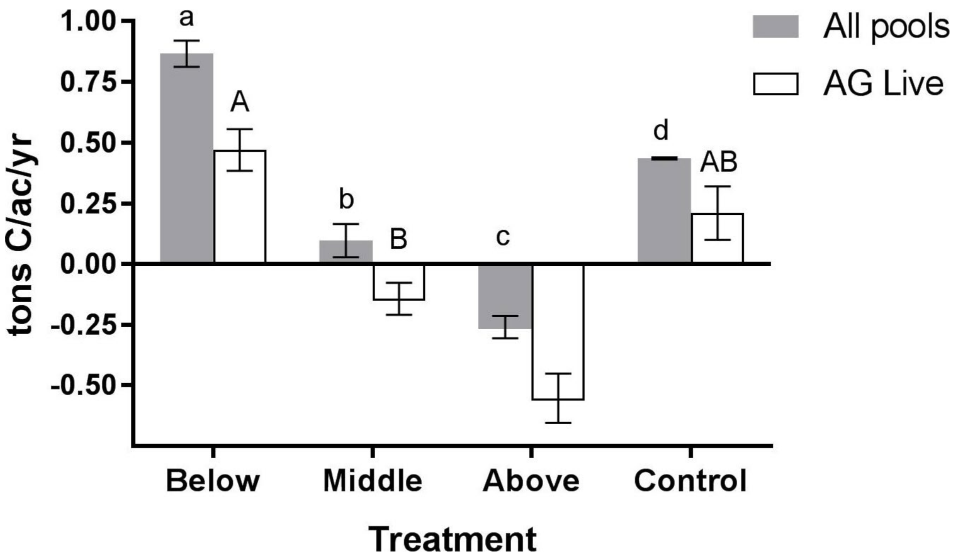


Figure 2.—Average annual change in carbon stock (tons/acre/year) for the study period 1975-2012. Shaded bar: all carbon pools, white bar: aboveground live tree carbon only. Error bars are standard error of the mean. Statistical comparisons are indicated by uppercase letters for live tree pool. Treatments with the same letter are not significantly different; otherwise, treatments are significantly different (including when no letter is present). For the rate of average annual change in total carbon stock all treatments are significantly different from each other and no letters are present.

We can also assess the effects of the treatments over time by considering average annual change for the duration of the study; stocks and stock changes each provide insight on the carbon consequences of a management practice, and depending on management objectives, one quantity may be more useful than the other. The time frame of the analysis strongly affects the rate of average annual change; rates may vary dramatically according to a particular management treatment over shorter and longer time frames. Here we consider the rates for the time span for which measurements are available: 1975-2012. The change of carbon stocks show significantly different rates in all treatments (Fig. 2; gray bar), ranging from 0.87 tons C/acre/year for the thin from below treatment to -0.26 tons C/acre/year in the thin from above treatment; the control mean is 0.43 tons C/acre/year. As with the standing carbon stocks, we can also calculate the rate of change in aboveground live tree carbon (Figure 2; white bar), and the thin from above treatment shows a change of -0.55 tons C/acre/year, significantly lower than the other treatments. This contrasts sharply with the average increase of 0.47 tons C/acre/year in live tree carbon in the plots thinned from below (unthinned controls added an average of 0.21 tons/acre/year).

DISCUSSION

When the Hoover and Stout study was published in 2007, few studies had investigated the carbon consequences of thinning or other silvicultural treatments. Since that time a growing body of literature, both international and domestic, has examined this topic. In many cases the same approach is used; analyzing data from past or ongoing silviculture studies to glean insight on the possible effects of management practices on forest carbon storage. These studies may report carbon stocks, rates of change in stock, or both. Hoover and Stout (2007) found that the way a stand was thinned could have a significant impact on both the carbon stored in the stand and the rate of carbon accumulation. They advised caution when employing thinning techniques that could substantially alter stand structure. Recent studies report varied results. Zhou et al. (2013) conducted a meta-analysis that included data from 81 studies (from a range of forest types around the world) that addressed the effects of partial cutting on carbon storage, forest structure, or both; levels of cutting intensity and time since cutting varied across the studies. Results were grouped into light (<34 percent), moderate (34-67 percent, and heavy (≥67 percent) cutting; outcomes were also analyzed with all results in a single pool. Zhou et al. (2013) also reported that overall, carbon stored in aboveground live trees declined by an average of 43.4 percent (rates were not reported) relative to uncut control plots. In the light intensity group, the average decrease was 28.2 percent, and the moderate and heavy cutting groups showed similar declines with 42.2 and 49.2 percent, respectively. Stand BA and volume were also lower in cut plots, and diameter growth was greater. A significant increase in understory carbon stock was also reported for all cutting intensity groups.

Other investigators have found varying results, depending on forest type and thinning method. D'Amato et al. (2011) analyzed results from several red pine (*Pinus resinosa*) and northern hardwood thinning studies initiated between 1949 and 1957 in the Upper Great Lakes region. Studies focused on stocking level, thinning method, cutting cycle length, or a combination of factors. They considered both carbon stock and accumulation rate and assessed only aboveground biomass in live trees. The results from the stocking level studies were similar and reflect typical stand dynamics: carbon stocks fluctuated in response to thinning treatments but were related to stocking level and stand age. Carbon accumulation rates were also generally related to stand age and declined over time. In the red pine thinning method study, the rate of carbon accumulation declined over time, and in contrast to Hoover and Stout (2007) was highest in the stands thinned from above compared to those thinned from below or with a proportional approach. Carbon stocks were also related to stand age and thinning method; the lowest stock was found in the stands that were thinned from above compared to the other approaches. A separate red pine cutting methods and stocking level study was also considered by D'Amato et al. (2011). Results were similar and revealed that stocks and rates were affected by stand age, stocking level, and thinning method as well as interactions among those factors. In general, they report that the rate of carbon accumulation decreased with stand age, and that differences in rates within a thinning method were attributable to lower rates at the 74-square-foot stocking level. Carbon accumulation rates were lowest in the stands thinned from below; the thin from above and proportional treatments did not differ. Carbon stocks increased with stand age and stocking level; thinning method had an effect only at the lowest level of stocking, where both the thin from above and thin from below treatments had lower carbon stocks than stands that were thinned proportionally. Schaedel et al. (2017) investigated the effects of early precommercial thinning in western larch (*Larix occidentalis*, again, using a historical study) in Montana; stands were thinned from below to range of density levels (target levels 200, 360, and 680 TPA). The number of entries also varied. At each targeted density, plots received one, two, or four entries; the target density was reached at the last entry. Unthinned control plots had the highest carbon stocks, but this difference was not significant; live aboveground carbon stocks were not affected by the thinning treatments, and the number of entries had no effect at any density level. Understory carbon did differ between treatments, with higher understory stocks occurring at lower overstory densities, similar to the findings of Zhou et al (2013).

Keyser (2010) used data from 118 plots in yellow-poplar (*Liriodendron tulipifera*) forests in the southern Appalachians to explore the effects of thinning on carbon storage, taking site quality into account. Plots were thinned from below to a residual BA ranging from 40 to 150 square feet per acre; most of the plots were thinned a second time to the same target approximately 6 years after the first treatment (the analysis excluded plots that received a single thinning). Keyser (2010) reported that on an average quality site, plots thinned to 130 square feet per acre stored 28 percent more carbon in live aboveground tree biomass than plots thinned to 85 square feet per acre and 78 percent more than those thinned to 40 square feet per acre (the original study design did not include unthinned controls).

Keyser also calculated carbon in harvested wood products. When this was factored in, the more heavily thinned plots still stored less carbon than the more lightly thinned plots throughout the study. Site quality also affected carbon storage; more carbon was stored in plots with a higher site index. The effect of site quality was more pronounced at lower density levels. For example, at a site index of 36 plots thinned to 40 square feet per acre stored 22 percent more carbon than plots with a site index of 26, and at the 130-square foot density level a plot of site index 34 had a predicted carbon storage of just 12 percent more than a plot with a site index of 26.

Moore et al. (2012) took another approach. They used data from inventory plots in the Great Smoky Mountains National Park with the Forest Vegetation Simulator to examine the effects of various management scenarios in a forest dominated by red spruce (*Picea rubens*) and Fraser fir (*Abies fraseri*) over a 100-year time frame. They simulated no-management, uneven-age management, and even-age management scenarios and assessed the effects of elevation and site index. Within each elevation band, site index had a minimal effect. Elevation was an important factor; growth increased with decreasing elevation. In every elevation group, the uneven-age scenario stored less carbon than the even-age or no-action scenarios; both regimes maintained a positive slope throughout the simulation period. In contrast, the no-action scenario always had the highest carbon stocks for the first half of the simulation, then slowly leveled off. Differences were more pronounced in the low- and mid-elevation bands, where the even-aged and no-action options had similar carbon stocks at the end of the simulation period, and the uneven-aged scenario showed clearly lower stocks; differences were smaller in the high-elevation band.

CONCLUSIONS

Precommercial thinning and partial harvesting have led to varying outcomes on carbon storage, but a few key themes emerge. In some cases, partial harvesting has led to a decrease in stand carbon storage that has persisted for several decades; in others, thinning has either had no effect on carbon stocks or has led to an increase in carbon stock, the rate of carbon accumulation, or both. Site quality, stand age, and elevation may all affect the outcome of a thinning treatment, with interactions between the factors, and should be taken into account when planning management actions, because thinning to a given density level on a high-quality site is likely to produce a different result than on a low-quality site. Stand structure also needs to be considered; in several studies cited here, thinned stands showed a decrease in overstory carbon accompanied by a significant increase in understory carbon, which could compromise management objectives.

In the Kane Experimental Forest example, the treatments were applied specifically to gather data to inform the development of SILVAH, and as such do not represent the manner in which thinning treatments are applied as part of a management plan. For example, tree species and quality were not considered when selecting stems for removal. That said, the nature of the treatments illustrates some important lessons about the importance of stand structure that are useful to managers who are considering the carbon consequences of silvicultural prescriptions. For example, the extreme thin from above treatment resulted in a situation where the suppressed stems could not respond well to release, and over the course of the 35-year study period these stands showed a significant decrease in aboveground live tree carbon, net volume, and BA and had lower merchantable medial diameters than the other treatments or the unthinned stands. The thin from below treatment, however, showed higher rates of carbon accumulation and greater carbon stocks, as well as net volume, diameter, and BA. D'Amato et al. (2011) also reported that the type of thinning applied affected carbon stocks and rates, with results varying across studies. An important outcome of that study is that the type of thinning often had an effect at only the lowest density level.

In summary, thinning does remove carbon from a stand; however, such treatments may lead to an increase in carbon stocks or rates of accumulation, or both. Density level, site index, elevation, stand structure, and management objectives must be carefully considered when planning a thinning treatment aimed at increasing forest carbon storage. Care should be taken not to compromise long-term stand growth with treatments that result in understory capture of growing space or the release of stems not capable of responding. With proper planning, thinning can be an important tool for advancing not only sustainable timber management objectives, but also enhancing forest carbon storage.

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The content of this paper reflects the views of the author, who is responsible for the facts and accuracy of the information presented herein.

APPENDIX 1
Training session agenda

Allegheny Society of American Foresters
Annual Summer Training
September 20 – 22, 2017 - Park Inn, Clarion, PA

"SILVAH: 50 Years of Practicing Sustainable Forestry and Counting"

Science Delivery Objective: To celebrate 50 years of science conducted under the SILVAH umbrella by:

- Reviewing its history and use
- Sharing the current state of science and management practice for research stimulated by SILVAH

Wednesday, September 20, 2017

8:00 AM – 6:00 PM Registration

9:45 Begin loading buses for field tour

10:00 AM – 6:00 PM Field tour to Kane Experimental Forest and surrounding landscape. SILVAH guidelines for regeneration, vegetation management, thinning, current research on deer impact, changes in regeneration ecology, forest health, fertilization, wildlife habitat, and carbon sequestration. (Bus transportation and box lunch incl.)

3:00 – 6:00 Exec Committee Meeting (transportation from tour to Park Inn provided)

7:00 – 9:00 Icebreaker/Social Reception

Thursday, September 21, 2017 *(6.5 CFE credits)*

7:00 – 8:00 Registration; Breakfast on your own

8:00 Exhibits open; raffle items on display

8:00 – 8:10 Welcome, Housekeeping & Introduction - Brock Sanner, Plateau Chapter Chair

8:10 – 8:30 "NW PA, Cherry capital of the world" - Sue Swanson, Executive Director ofAllegheny Hardwood Utilization Group (AHUG)

SILVAH: History and Development

8:30 – 9:00 Keynote Address: "The Origins and Early History of the SILVAH System" - David A. Marquis

9:00 – 9:30 "The Development of Management Science Under SILVAH" – Susan L. Stout

9:30 – 10:00 BREAK

10:00 – 10:30 "Managing with SILVAH Support" – Jim Grace

10:30 – 11:00 "Deer and Forests" – Alex Royo

11:00 – 11:30 "Forest Vegetation Management" – Todd Ristau and Steve Horsley

11:30 – 12:00 "Expanding SILVAH to the Mixed Oak Forests of Mid Atlantic Region" – Patrick Brose

12:00 – 1:00 LUNCH

Concurrent Sessions (1:15 to 4:15)

1. SILVAH: Oak and Allegheny Norther Hardwood Species

1:15 – 1:45 "Common Oak Regeneration Prescriptions" – Pat Brose

1:45 – 2:15 "Preliminary Results of the OAK: SILVAH Assessment" – Laura Leites and Scott Miller

2:15 – 2:45 "OAK SILVAH in Ohio at the Landscape Scale" – Joanne Rebbeck and Matt Peters

2:45 – 3:15 BREAK

3:15 – 3:45 "SILVAH & FIA: Taking SILVAH's Regen Guidelines to the Regional Level" - Will McWilliams

3:45 – 4:15 "SILVAH's Thinning Guidelines" – Chris Nowak

4:15 – 5:00 "Sugar Maple Decline and Lessons Learned about Allegheny Plateau Soils and Landscapes" – Bob Long

2. SILVAH: Wildlife, Invasive Plants, NED and related software

1:15 – 1:45 "NED and the NED/SILVAH Coalition" – Mark Twery

1:45 – 2:15 "Silviculture and Bird Habitat" - Scott Stoleson

2:15 – 2:45 "Research to Support Wildlife Habitat Associations in SILVAH and NED" – Scott and Linda Thomasma, Helene Cleveland

2:45 – 3:15 BREAK

3:15 – 3:45 "Impacts of Operational Herbicide Treatments on Non-Target Plants, Birds, and Beetles" – Todd Ristau and Scott Stoleson

3:45 – 4:15 "Forest Vegetation Management of Invasive Species" - Kimberly Bohn

4:15 – 5:00 "Managing Carbon in Allegheny Hardwoods" – Coeli Hoover

End of Concurrent Sessions

6:00 Cocktail Hour

7:00 BAR-B-Q Cookout (next door to hotel, 1/4 mile); including drawing for one raffle item

FRIDAY, September 22, 2017 *(2.0 CFE Credits for 9:00 – 11:30 sessions)*

7:00 – 8:00 Chair's Breakfast with Guest Inspirational Speaker Stephanie Gottschalk (all are welcome)

8:00 – 8:30 Division Business Meetings

8:30 – 9:00 Allegheny SAF Section Business Meeting

9:00 – 9:30 "Changes in Black Cherry" – Bob Long

9:30 – 10:00 "Preliminary Dominance Probabilities in Allegheny Hardwood and Mixed Oak" – Pat Brose

10:00 - 10:30 BREAK & final offer to buy raffle tickets

10:30 – 11:00 "Fertilizing Allegheny and Northern Hardwood Stands" – Todd Ristau

11:00 – 11:30 "The Next 50 years of SILVAH, Silviculture and Forest Stewardship" – Susan Stout

11:30 Wrap up & announce raffle winner – Brock Sanner

12:15 – 3:30 Optional Field Tour to Clear Creek State Forest for a Full Overview of SILVAH: Oak Research and Guidelines (No cost. Participants will caravan in their own vehicles and bring their own lunch.)

APPENDIX 2

List of Attendees

Timothy Ackerman
PA DCNR, Bureau of Forestry
Edinboro, PA

David Andrus
Generations Forestry
Coudersport, PA

David Babyak
Babyak Forestry Services
Indiana, PA

Michael Barton
Michael Barton Forestry Consulting
Sidman, PA

William Blankenship
Forest Investment Associates
Atlanta, GA

Andrew Blazewicz
Andrew Blazewicz, Jr., Consulting Forester
Holidaysburg, PA

Kimberly Bohn
Penn State Extension
Smethport, PA

Patrick Brose
USDA Forest Service
Irvine, PA

Robert Carlberg
Carlberg Forestry, Inc.
Butler, PA

Richard Cary
Forestland Consulting
Orefield, PA

Helene Cleveland
USDA Forest Service (Retired)
Dexter, NY

Mike Clutter
Forest Investment Associates
Atlanta, GA

Woody Colbert
Resource Enterprises Service Team
State College, PA

David Cole
PA DCNR, Bureau of Forestry
Clarion, PA

Richard Conrad
PA DCNR, Bureau of Forestry
Summerville, PA

Richard Constantino
Forecon, Inc.
Falconer, NY

Tracy Coulter
PA DCNR, Bureau of Forestry
Harrisburg, PA

Douglas D'Amore
PA DCNR, Bureau of Forestry
Renovo, PA

John Daugherty
Timber Resources Unlimited, LLC
Knox, PA

David Daut
Domain Timber Advisors, LLC
Berlin, VT

Brian Deeb
Weaber Lumber Company
Lebanon, PA

John Denning
Maryland DNR
Oakland, MD

Luke Dillinger
Domtar
Johnsonburg, PA

Donald Dorn
USDA Forest Service (Retired)
Sheffield, PA

Jarrid Doyle
PA Dept of Military & Veterans Affairs
Williamstown, PA

Andrew Duncan
PA DCNR, Bureau of Forestry
Harrisburg, PA

Michael Eckley
The Nature Conservancy
Williamsport, PA

Bradley Elison
PA DCNR (Retired)
Pottsville, PA

Carlen Emanuel
Appalachian Trail Conservancy
Kearneysville, WV

Curtis Eshleman
Timberlink Consulting, LLC
Doylestown, PA

Victor Fabrycki
Penn Forestry Company, Inc.
Blue Ridge Summit, PA

James Finley
Penn State University
Port Matilda, PA

Josh Flad
Green Leaf Consulting Services
Beach Lake, PA

Gary Frank
PA DCNR (Retired)
Brookville, PA

Dennis Galway
Galway Forestry Services
Bernardsville, NJ

Donna Galway
Galway Forestry Services
Bernardsville, NJ

Matt Gayley
Collins-Kane Hardwood
Kane, PA

John Gifford
Forecon, Inc.
Falconer, NY

Gary Gilmore
PA DCNR, Bureau of Forestry
Luthersburg, PA

Joseph Glover
F & W Forestry
Strattenville, PA

Stephen Goodman
Internal Revenue Service (Retired)
Hillsdale, NJ

Lake Graboski
Student
Berwick, PA

James Grace
Penn State University/PA DCNR (Retired)
Camp Hill, PA

David Gustafson
Pennsylvania Game Commission
Harrisburg, PA

Christopher Guth
Northwest Hardwoods
Clarion, PA

Todd Hagenbuch
Arborchem/Asplundh
West Chester, PA

Hermann Hampel
Danzer Forestland, Inc.
Darlington, PA

Thomas Hartman
Kocjancic Forestry Solutions
Kane, PA

Constance Hausman
Cleveland Metroparks
Cleveland, Ohio

Shannon Henry
PA Dept of Military & Veterans Affairs
Annville, PA

Dan Hicks
Collins-Kane Hardwood
Kane, PA

Paul Higby
Collins-Kane Hardwood (Retired)
Sheffield, PA

Andrea Hille
USDA Forest Service
Warren, PA

Coeli Hoover
USDA Forest Service
Durham, NH

Leslie Horner
Penn State University
University Park, PA

Stephen Horsley
USDA Forest Service (Retired)
Russell, PA

Michael Hovatter
LandVest
Kane, PA

Jonathan Howard
Endless Mountains Land Services, LLC
Tunkhannock, PA

John Hudson
Hudson Forestry Services, LLC
New Castle, PA

Dan Imbrogno
Collins-Kane Hardwood
Kane, PA

David Jackson
Penn State Extension
Bellefonte, PA

Michael Jacobson
Penn State University
University Park, PA

Kenneth Jolly
Maryland DNR
Annapolis, MD

Kenneth Kane
Generations Forestry
Kane, PA

Kenneth Kane, Jr.
Generations Forestry
Kane, PA

Ned Karger
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Kane, PA

Tom Kase
Collins-Kane Hardwood
Kane, PA

Robert Kirkpatrick
Collins-Kane Hardwood
Kane, PA

Edward Kocjancic
Kocjancic Forestry Solutions
Kane, PA

Steven Koehn
USDA Forest Service
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Dustin Krause
PA Dept of Military & Veterans Affairs
Pine Grove, PA

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Cleveland, Ohio

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McKain Forestry Services
Kennerdell, PA

Will McWilliams
USDA Forest Service
Newtown Square, PA

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Jersy Shore, PA

Charles Merroth
PA DCNR (Retired)
Warren, PA

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Russell, PA

Patrick Miller
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Joanne Rebbeck
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Harrisburg, PA

Todd Ristau
USDA Forest Service
Irvine, PA

Josh Rittenhouse
Indiana University of PA
Indiana, PA

Terry Robison
Cleveland Metroparks
Cleveland, Ohio

Bryan Rose
Arborchem/Asplundh
Brockport, PA

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This report represents proceedings of the Allegheny Society of American Foresters training session titled "SILVAH: 50 Years of Science Management Cooperation." This meeting celebrated a unique and long-lasting community of practice that includes forest and natural resource managers and scientists. SILVAH originated in northwestern Pennsylvania in the late 1960s. Over time, the research results, shared efforts, and training sessions led to decision support software and all became known as SILVAH, and the geographic range of the community expanded. This published proceedings includes 12 papers that describe the origins and early history of the community of practice, the current state of science and management guidelines as presented at the conference, as well as a paper that explores the factors that contributed to its long-term success.

KEY WORDS: SILVAH, silviculture, science-management cooperation, Allegheny hardwoods, mixed oak forests, white-tailed deer, herbicides, wildlife habitat, decision support, plant habitat, carbon sequestration and storage, sugar maple decline, forest health, forest vegetation management

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