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silviculture

The SILVAH Saga: 40+ Years of Collaborative Hardwood Research and Management Highlight Silviculture

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The advent of even-age management in eastern forests in the 1960s improved regeneration of shade-intolerant and shade-intermediate species through much of the region. However, in the Allegheny hardwood stands of northern Pennsylvania, half of the even-aged regeneration harvests failed to create new forests. USDA Forest Service Research and Development (FSR&D) initiated a partnership with federal, state, industrial, and private forest landowners to solve this problem using silviculture. The partners developed inventory procedures and decision charts to identify regeneration assets and barriers as well as silvicultural treatments to mitigate the barriers. FSR&D training sessions ensured a common silvicultural vocabulary and common practices, later computerized in the SILVAH decision support system. In 2000, the partnership expanded SILVAH to mixed-oak forests of the mid-Atlantic region. Land management agencies in Pennsylvania and several other eastern states have adopted SILVAH. It provides a consistent framework for research-management cooperation, for sharing the results of silvicultural research, and for making silvicultural decisions in the forest types covered by the system.

Keywords: research-management cooperation, decision support, Allegheny hardwoods, mixed-oak forests

Many forest plans emphasize the advantages of adaptive, science-based planning and management for contemporary forestry (Pennsylvania Department of Conservation, and Natural Resources, Division of Forestry 2007, Ohio Department of Natural Resources, Division of Forestry 2010, US Federal Register 2012). Differences in culture and motivation between land managers and scientists can sometimes act as a barrier to true science-based management (USDA Forest Service 1995, 1997). Since the late 1960s, managers and scientists have been overcoming these cultural differences to create a community of practice anchored in silviculture for sustainable forestry, starting in the Allegheny hardwood forests of northwestern Pennsylvania and more recently extending to mixed-oak forests. This partnership in the northcentral Appalachian region provides evidence that managers and scientists can collaborate to solve important management problems and may provide a model for building and sustaining such cooperation.

During the 1960s, researchers and forest managers in the mixed-hardwood forests of the eastern United States began to embrace even-age silviculture to increase the representation of shade-intolerant and shade-intermediate species in natural regeneration (Roach and Gingrich 1968). While the practices of even-age silviculture, specifically large clearcuts, in eastern hardwood forests led to an important policy controversy (see Miller 2014), they generally achieved their regeneration goals (Leak 1961, Trimble 1971, 1972, Godman and Tubbs 1973). In northwestern Pennsylvania, home to the valuable Allegheny hardwood forest type with its high concentration of shade-intolerant black cherry (*Prunus serotina*), however, complete harvests of even-age overstories led to regeneration failures about 50% of the time (Marquis 1981). At a 1967 local Society of American Foresters meeting in Ridgway, Pennsylvania, forest managers appealed to the Director of the Northeastern Forest Experiment Station to provide increased research attention to the region and its regeneration difficulties. Additional scientists were assigned to the research station associated with the Kane Experimental Forest to address this problem.

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Figure 1. A photograph from an early Allegheny Plateau regeneration study. An earlier harvest had resulted in regeneration failure, but in 87% of the regeneration failures, erecting a fence to exclude white-tailed deer promoted development of desirable regeneration.

Early Research Focused on Regeneration Problems

Collaboration with managers was important to the scientific staff from the beginning, perhaps because much of the staff was new to the region or perhaps because managers had asked for the additional research support. Managers had many theories about causes of regeneration failures, and these became the hypotheses that drove the research team's early studies. These studies were often conducted in collaboration with land managers and land management agencies. For example, one important early study focused on 65 operational even-aged regeneration harvests on the Allegheny National Forest. Scientists and technicians gathered data about preharvest conditions, focusing on soils, vegetation, and overstory species composition. Forty-six percent of the harvests failed to replace forest with forest, and half regenerated to species composition similar to that in the preharvest stand (Grisez and Peace 1973). An early lesson was that the abundance of advance regeneration was the single best predictor of which areas would regenerate successfully after harvest (Marquis et al. 1975).

In a follow-up study, managers and scientists worked together to test a hypothesis that browsing by white-tailed deer (*Odocoileus virginianus*) was an important cause of regeneration failure. Deer-excluding fences were erected in some of the failed regeneration harvests of the previous study, and in 87% of the failures, simply erecting a deer-excluding fence allowed desirable regeneration to develop (Figure 1) (Marquis 1981). Fertilization tests, also on national forestlands, indicated that cherry growth was responsive to a mix of nitrogen and phosphorus (Auchmoody 1982). Vegetation tests conducted on state forests and industrial lands, as well as national forests, suggested that some common understory plants such as hay-scented (*Dennstaedtia punctilobula*) and New York fern (*Thelypteris noveboracensis*), beech (*Fagus grandifolia*) root suckers, and striped maple (*Acer pennsylvanicum*) cast so much low shade that regeneration could not establish or grow until these were removed (Horsley and Bjorkbom 1983, Horsley and Marquis 1983). Marquis (1979) began to identify silvicultural strategies focused on two-step shelterwood harvests to promote advance regeneration, and Roach (1977) developed tools for assessing relative density in maturing stands for better control of intermediate thinnings.

Development of Management Guidelines

As these research results accumulated, scientists, managers, and a Pennsylvania State University extension forester named Sandy Cochran worked to translate them into management guidelines. Roach and Marquis were at the forefront of a movement to strengthen the quantitative side of the art and science of silviculture, and with the others, they developed quantitative inventory procedures to help managers choose a silvicultural pathway for individual stands. The inventory procedure combined traditional overstory procedures, usually based on a variable-radius plot, and an inventory of forest understory conditions designed to determine the balance between advance regeneration, interfering plants, and soil conditions.

The understory inventory relied on the "stocked plot" concept. Rather than basing decisions on the average number of advance seedlings per acre, decisions are based on the proportion of plots that meet acceptable stocking criteria based on research studies (Grisez and Peace 1973, Marquis et al. 1975).

Management and Policy Implications

The SILVAH system has become the anchor for an effective system of research-management cooperation across a broad region. Early success in solving critical management problems such as regeneration failure was important for building sustained cooperation, and for highlighting the important role of silviculture in successful sustainable forestry. The SILVAH focus on assessing current conditions in the understory and overstory using objective, science-based criteria resulted in a community of silvicultural practice that sustains diverse species and values. Over time, ties between managers and scientists have strengthened as managers helped set research agendas, and scientists came to depend on managers to help identify research sites, share observations, and provide in-kind services. Annual training sessions ensure that managers and scientists have regular interactions and share a common framework and vocabulary for discussing management challenges. The training sessions force scientists to resolve apparently contradictory research results and to update the SILVAH framework as new research results accumulate. Because scientists and managers share experience, vocabulary, and a framework for exploring and explaining forestry challenges, they are able to work effectively together to communicate with policymakers and the public and to demonstrate the application of new silvicultural practices together. Although the particulars of forest ecology addressed by SILVAH are specific to one geographic region and a few forest types, the principles of regular engagement between scientists and managers, a shared vocabulary and framework for describing problems and solutions, and cooperative work on shared places are likely to foster increased research-management cooperation in many contexts.

Figure 2. Individuals who played key roles in the relationships and research that form the foundation of the SILVAH system. Top row: Ben Roach, David Marquis, and Ted Grisez. Bottom row: John Bjorkbom, Lew Auchmoody, Steve Horsley, Rich Ernst, and Jim Redding.

Simulations of stand development helped identify criteria for stand maturity, whereas an extensive thinning study identified the range of overstory density within which the best balance between individual tree and stand growth occurred (Roach 1977). By 1976, these guidelines were sufficiently well developed to support 1-day training sessions on regeneration and stand culture. Figure 2 shows many of the research leaders whose contributions initiated the SILVAH system.

Training Sessions Promote Adoption

From the beginning, session organizers recognized the importance of interactions among managers from different organizations and scientists to promote adoption of guidelines and continued research progress. The sessions included a balance among presentations, field trips, and actual practice that included collecting inventory data, analyzing it to identify a recommended prescription, and implementing the prescription by marking a stand. Although the organizers initially imagined that the training sessions would be offered for a few years until the most interested managers had taken the classes, it soon became obvious that the regular interaction was beneficial for all concerned. Field visits to places where failure would have been expected but where the guidelines had resulted in successful regeneration were especially informative. That inspired many organizations to make very costly commitments to a better inventory process, despite the fact that it required additional time and could only be conducted within the summer months to include understory plots (Figure 3). The training sessions have been offered annually every year but one since 1976; eventually sessions gave rise to a textbook and publication of the slides used in the course (Marquis et al. 1992, Marquis 1994).

The cross-fertilization of perspectives and experiences was so important that a spinoff program of annual multiagency workshops related to herbicide practice developed shortly after the original training sessions. While scientists focused on careful studies of which herbicides, at which rates, and at which dates of application resulted in the best efficacy for regeneration success (Horsley 1989, 1990a, 1990b), land managers were actively engaged in equipment improvement and culturing a new forest-related industry.

A third research-management collaboration grew out of the regeneration and training session efforts. As many managers had suspected and early work confirmed, deer impacts across the Allegheny hardwood region represented important barriers to natural regeneration. Beginning in the mid-1970s, the team of scientists and managers designed and implemented a landmark study of the impacts of deer on regeneration processes. At four replicate locations, on land managed by the Allegheny National Forest, the Pennsylvania Bureau of Forestry (hereafter Bureau of Forestry), the Pennsylvania Game Commission, and one industrial partner, fences were erected around managed forest enclosures with four different deer densities at each location. The design of the study and construction of the study sites engaged representatives of many organizations, from land managers through the Society of American Foresters local chapter. Detailed vegetation measurements sus-

Figure 3. A forester tallying an understory inventory plot stocked with tall woody interference.

tained through time provided landmark evidence of different ecosystem development trajectories that influenced the composition and structure of deer, bird, and insect communities (Tilghman 1989, deCalesta 1994, Horsley et al. 2003, Nuttle et al. 2011). Equally important, managers and scientists worked together to share the research results with a wide diversity of audiences, from land and resource managers through hunters and policymakers.

SILVAH Software Introduced

During the early training sessions, calculations to support the quantitative decision criteria were conducted by hand. Scientists familiar with the calculations would circulate among participants, explaining and checking the calculations. Soon, Richard Ernst, a biometrician on the Northeastern Forest Experiment Station team, began programming the calculations into his handheld calculator, and as computers entered the forestry business, the calculations to support the silvicultural decisions associated with the silviculture of Allegheny hardwoods guidelines were programmed into a decision support system known as SILVAH (Marquis and Ernst 1992).

By the early 1990s, most scientists at the Warren, Pennsylvania, Northern Research Station facility were regularly engaged in the training sessions. The shared commitment to presenting a coherent, objective, and complete approach to analyzing current conditions in the SILVAH framework began to influence the way research results were presented. As results from the deer study accumulated, for example, SILVAH regeneration stocking thresholds were modified to reflect the fact that fewer seedlings were required for a plot to be considered stocked when deer densities were lower than those observed in the late 1960s and early 1970s. Conditions under which construction of a deer-excluding fence would help regeneration succeed were identified and integrated into the prescriptions. Scientists also observed that pin cherry (*Prunus pennsylvanica*), a species so highly preferred by deer that it had rarely been seen in regeneration, could become a barrier to regeneration success in stands regenerated inside fences or where deer densities were locally quite low. New guidelines for assessing the importance of pin cherry were added to SILVAH (Ristau and Horsley 1999). Results from the thinning study showed that stands with high proportions of black cherry grew better at higher residual densities than those with lower proportions (Nowak 1996).

SILVAH Expands to Mixed-Oak Forests

By the 1990s, the Allegheny National Forest and the Bureau of Forestry adopted the SILVAH system, as the management guidelines came to be known, to support silvicultural decisionmaking in Allegheny and northern hardwood forests under their stewardship, and many private industrial forests were also applying the principles. When the forests of the Bureau of Forestry sought certification under the Forest Stewardship Council criteria, the reviewers commented favorably on the objectivity and consistency of the decision criteria and recommended that the Bureau seek a similar system for its mixed-oak forests (Scientific Certification Systems 1997).

The Bureau of Forestry convened a committee of scientists and managers to address this recommendation. It included faculty from Penn State and Forest Service scientists from the Warren and Morgantown, West Virginia, laboratories. The engagement of the Bureau of Forestry with scientists from both institutions reflected the community of practice that had developed around the SILVAH system, as managers felt confident asking researchers to take on a specific management challenge. The process that emerged was quite unique and remarkable. Participants worked to translate the important results from research elsewhere, most notably, Missouri and North Carolina, into the SILVAH framework. Brose et al. (2008) took the lead on translating the existing information into the SILVAH format. Equally important, the group identified research gaps and priorities to strengthen the recommended guidelines through time, and because the Bureau of Forestry has both regeneration and research funding available, this group has been able to make a very substantial investment of dollars, lands, and in-kind support for silvicultural research to fill those gaps. The group also identified a process to engage foresters in testing the proposed new SILVAH procedures before full-scale adoption.

A critical breakthrough in adapting SILVAH to mixed-oak systems was developed by Patrick Brose in his early months on the SILVAH team. Because of the root-cen-

Figure 4. Patrick Brose demonstrates the root characteristics of a competitive oak seedling.

tric growth patterns of oak seedlings, the appropriate silviculture for oak regeneration depends on the stage of root development of oak advance seedlings (Figure 4). SILVAH for mixed oaks recognizes three distinct classes of oak (and hickory and walnut) seedlings based primarily on their root collar diameters. The largest seedlings, called competitive, (those ready for release by a final harvest) are those with a root collar diameter of $\geq$0.75-in. The next class, called established, are those with sufficient root development to survive the first commercial cut of a shelterwood treatment, or the prescribed fire of a shelterwood-burn sequence (Brose et al. 1999). They have root collar diameters between 0.25 and 0.75 in. The smallest class, with root collar diameters of $<$0.25 in., is called new oak; when these are present, harsh silvicultural treatments, such as prescribed fire or major openings in the canopy, are to be avoided until they have become established. There are stocking standards for each of these classes.

In June 2000, with beta-test-ready inventory procedures and decision charts for a new SILVAH-Oak, scientists developed training materials similar to those used in the Allegheny hardwood sessions. The Northeastern Research Station, Bureau of Forestry, and Penn State collaborated to design a 1-day workshop to share the new inventory processes and decision charts with the Bureau of Forestry field forestry staff. Penn State provided a computer-equipped classroom, and forest managers, working with Brose, selected sites for practice inventory exercises. In a single week, more than 90 Bureau of Forestry foresters and some potential users from other agencies went through a single-day training session with explicit expectations that they would try the new procedures and decision charts on their home forests through the growing season and keep detailed notes about what worked and what did not. There was great concern about the practical implications of creating inventory categories based on root collar diameter. System designers suggested that rather than actually assess root collar diameter on every seedling, users should test borderline stems only on the first few plots. For example, seedlings not yet 3 ft tall, but with multiple branches and many leaves, might have a larger root collar than their height suggested, Once foresters got a "feel" for the conditions in any particular stand and what that meant for seedling classification, they could base their inventory on aboveground attributes. In the fall of 2000, one representative from each district brought their comments back to the scientists, and adjustments were made. The biggest change made at that time was recognition of the easier route to successful oak regeneration in low site class stands, which was eventually captured in a separate decision chart.

SILVAH Beyond Pennsylvania

Once the adaptations suggested by the beta testers were made, full incorporation of the new guidelines and decision charts into the computer software and a new, week-long training session began in earnest. Core staff included Gary Miller and Kurt Gottschalk of the Northern Research Station Morgantown, West Virginia, laboratory, who had been full partners in the development of the mixed-oak guidelines. They initiated training sessions in West Virginia that involved the full SILVAH team. As Joanne Rebbeck of the Northern Research Station Delaware, Ohio, laboratory worked to bring SILVAH-Oak to Ohio, she and the Ohio chapter of The Nature Conservancy identified a need to address nonnative invasive species in SILVAH understory inventories. Pete Knopp, a programmer on the SILVAH project, developed the needed SILVAH module. To date, 4-day training sessions have been offered in West Virginia, Ohio, Maryland, and Kentucky, and near-annual sessions continue in Pennsylvania. A 1-day mini-training session was given in Indiana, and other states have invited the SILVAH team to offer training sessions as well.

Why Is SILVAH So Popular?

Managers and scientists agree that the simple explanation for the popularity of SILVAH fits perfectly with the theme of the 2013 Society of American Foresters convention—because "Silviculture Matters." Foresters and agencies faced with the challenge of achieving sustainable forestry for timber and wildlife objectives quickly realize that having a consistent, objective, and silviculture-based framework for organizing their own expert knowledge and field observations helps in communicating with each other, with their publics, with their bosses or subordinates, and with a team of scientists whom they know by name and area of expertise. They know, too, that manipulating the structure, density, and composition of forests is key to achieving a wide array of management objectives. Silviculture and SILVAH allow foresters to integrate consistent observations about overstory composition, structure, and density with observations about regeneration assets by species and size class and regeneration barriers in a systematic and quantitative way. SILVAH then ties these observations to specific silvicultural prescriptions such as prescribed fire, herbicide, or shelterwood cutting. Each prescription is recommended for a specific management objective or desired future condition when the data about stand conditions fall within a specified range. Thus, the decision support structure organizes our understanding of vegetative and site conditions, stand development, and the response of forest communities to planned disturbance and facilitates both discussion and practice. In fact, a current development in SILVAH has been the increasing engagement of agency wildlife staff concerned about the future of oak forests. As some of these participants began to understand the power of the silvicultural organizing principles, they initiated interactions with us to strengthen the specific wildlife aspects of the SILVAH system.

Summary

Across the region served by SILVAH, cooperation between managers and scientists strengthened as managers helped set research agendas, and scientists depended on managers to help identify research sites and to share observations and provide in-kind services. Annual training sessions ensure that managers and scientists have regular interactions and share a common framework and vocabulary for discussing management challenges. The training sessions force scientists to resolve apparently contradictory research results and to update the SILVAH framework as new research results accumulate. Because scientists and managers share experience, vocabulary, and a framework for exploring and explaining forestry challenges, they are able to work effectively together to communicate with policymakers and the public and to demonstrate the application of new silvicultural practices together. Although the particulars of forest ecology addressed by SILVAH are specific to one geographic region and a few forest types, the principles of regular engagement between scientists and managers, a shared vocabulary and framework for describing problems and solutions, and cooperative work on shared places are likely to foster increased research-management cooperation in many contexts.

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