Defining the Role of Silvicultural Research in the Northeastern Forest Experiment Station

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Abstract.—Research planning in the Northeastern Forest Experiment Station has followed a grass roots model for more than two years—ROADMAP, a research and development management plan. The goals for research within ROADMAP include understanding, protecting, managing, and utilizing forest ecosystems. There are nine research themes set to help achieve these goals, each with a set of research initiatives that describe contemporary and future science. Development of the "Silviculture and Resource Management Theme" has helped the Station define and communicate the role of silviculture to a variety of audiences. This paper presents the silvicultural statement developed by a core group of Station scientists.

INTRODUCTION

Research planning in the Northeastern Forest Experiment Station has followed a grass roots model for more than two years—ROADMAP, a research and development management plan[2]. This effort is grass roots because Station scientists are guiding and coordinating Station-level dedication to research problems, including resource allocations. Nine themes are being used by scientists to describe and plan Station research: Basic Processes, Disturbance and Ecosystem Dynamics, Forest Products and Use Economics, Inventory and Monitoring, Managing Forest Health, Silviculture and Resource Management, Social and Economic Dimensions, Systems Modeling and Integration, and Wildlife. The research of the Station is organized to provide regional, interdisciplinary, and long-term support for understanding, protecting, managing, and utilizing forest ecosystems in partnership with scientists at universities and in industry.

Each theme was developed by a team of scientists from across the Northeastern Forest Experiment Station. The "Silviculture and Resource Management" team had nine members, many considered core Station silviculturists and all co-authors of this paper.

Science at the Station exists along a continuum from basic science through application to management and policy. Each team's responsibility was to define where that team's position is along the continuum, that is, we had to define our role in the Station and then communicate it to our colleagues and stakeholders. In this paper, we describe the role of silvicultural research within the Station as developed for ROADMAP. Each team was given a list of questions to answer in a single statement. We modified this list as a framework for this paper.

WHAT IS SILVICULTURAL RESEARCH?

Silvicultural research provides options for practical, sustainable management of forests to produce a variety of outputs and outcomes. Options include different methods and guidelines for practical management of forest ecosystems to meet landowner objectives, and to sustain benefits in perpetuity (Nyland 1996). Included in this research is developing the ability and tools (models) to forecast likely outputs and outcomes from a given set of silvicultural treatments. Benefits achieved by silviculture include those directly or indirectly from the trees themselves, other plants, water, wildlife, and minerals found in forested areas, and a host of intangibles that people realize through recreation and other noncommodity uses (Nyland 1996).

Silvicultural research uses manipulative field experiments or computer simulations to test methods and practices for managing vegetation to achieve desired conditions. Density, structure, and species composition are directly altered by cutting, herbiciding, fertilizing, planting, pruning, firing, or otherwise disturbing vegetation. Treatments alter stand conditions to favor the regeneration or growth of desirable plant and animal communities, and positively affect ecosystem functions and processes such as the hydrologic cycle or energy transfer. Silvicultural research includes the study of linkages between ecosystem attributes and associated plant and animal communities.

Silvicultural researchers develop technical guidelines in the context of both ecological capabilities and social constraints. It is the responsibility of the research silviculturist to execute or instigate biological and ecological studies in support of the development of management guidelines and options, and to integrate new and existing basic information into those guidelines. In doing so, guidelines are likely to produce consistently predictable and sustainable outputs and outcomes, and research results will be more readily adapted to areas outside the study locale.

WHY SHOULD THE NE STATION CONDUCT SILVICULTURE RESEARCH?

The Station is located in an area of little federal ownership. The region's industry consists primarily of small- to medium-sized firms. Eighty-five percent of forest lands are held by non-industrial owners with small ownerships. The forest landowners in the Northeast do not have the resources or

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level of commitment to do long-term research necessary to develop silvicultural knowledge. The Station has a commitment to long-term research, and has an unparalleled base of long-term studies. Many studies established in the 1930's are just beginning to produce the intended research outputs for which they were established. Furthermore, landowner values change. New developments emerge from science. Technology is improved. Society's attitudes evolve. And the forest changes. All of these factors combined cause a continuing need for new silvicultural research.

Silvicultural research has been a mainstay of the Station for 75 years. Many laboratories were chartered and companion experimental forests established to conduct this research. The Station is conducting more than 80 long-term studies in association with Region 9's national forests, mostly on the Allegheny (n=31) and Monongahela National Forests (n=33). Most of these studies are maintained on the Kane and Fernow Experimental Forests. These studies, and dozens of other studies conducted with non-federal partners, are the Station's primary strength as a research organization and a testament to the Station's commitment to silvicultural research.

HOW WILL THIS RESEARCH BE USED?

A range of silvicultural options for multiple forest outputs and benefits will continue to be developed, both by refining and extending existing knowledge and developing new methods and guidelines. Customers to be served with these options include land managers (national forests, state agencies, industry, consultants), universities, Cooperative Extension, state Forest Stewardship programs, State and Private Forestry, environmental organizations, and the general public. Forest managers in the Eastern U.S. will make better decisions regarding forest manipulations and forest management because of our research. National Forest and state forest plan revisions, many slated for completion by the year 2000, will better incorporate silvicultural and resource management issues and solutions for a changing forest resource and changing client demands.

Most of the silvicultural guides developed over the past 75 years were developed by the USDA Forest Service. University curriculum in forestry prominently includes many of the silvicultural principles and practices developed by Forest Service researchers. As research results are published, new silvicultural knowledge is integrated into curricula to help produce well-trained professionals. Similarly, silvicultural researchers are keyed to directly interact with customers through a variety of training sessions, field tours, and other technology transfer activities.

Historically, silvicultural and resource management principles and practices have been well adapted by owners and managers of large land areas, but not by the Northeast's dominant body of forest-land owners—the nonindustrial private forest-land owner (NIPF). As the Northeast's forest matures, pressure to harvest the timber resource across the Eastern U.S. is increasing, especially on NIPF lands, so research must be applicable to these lands. We need to develop silvicultural guides that will allow NIPF's to make more informed decisions regarding the management of their forest lands.

WHO IS DOING THIS RESEARCH?

Centers were established over 50 years ago to provide regional coverage of the major forest types: northern conifer and northern hardwood (Durham, NH), northern hardwood and Allegheny hardwood (Warren, PA), Appalachian hardwood, transition oak, and oak-hickory (Parsons, WV) and oak-hickory (Delaware, OH) (Fig. 1). Each of these units is the steward of at least one experimental forest. Eight Station scientists are focused primarily on silviculture and resource management research in these four units, while the research program of an additional 25 scientists includes some research in this theme, for a total of 11 scientist years, or about 11 percent of Station resources, both staffing and dollars.

WHAT ARE THE RESEARCH INITIATIVES?

During the ROADMAP process, the team described the direction for silvicultural research in three major initiatives: regeneration, multiple tangible outputs, and intangible outcomes.

Regeneration Initiative

Developing regeneration practices that work for all ownerships is the foremost research initiative. Understanding regeneration patterns and processes is critical to sustainable resource management and a cornerstone of future silvicultural research. We will focus research on developing desired mixed-species regeneration in northern hardwoods and conifers, Allegheny and Appalachian hardwoods, northern conifers, and a variety of oak forest types, including transition oaks and oak-hickory. Fire as a tool will continue to be studied to regenerate the oaks. Planting guides will need to be refined and developed not just for oak, but for other species too. And for some species, especially oaks on mesic sites, maintaining the planting investment will mean a need for new research information on weeding and cleaning. Regeneration research will occur in even-age systems, uneven-age systems, and new practices will be developed for the emerging two-age system. This new system will be important as it relates to NIPF lands. Partial cuts made on private lands often result in two-aged stands.

Example No. 1.—Understory vegetation responses to thinning have received little study, primarily because the focus has been on the residual overstory trees. Understory responses to thinning may affect subsequent efforts to regenerate. Aesthetics and wildlife habitat may also be affected. We have begun to examine the long-term effects of thinning to different residual densities and structures on understory development (Yanai, in press). Study treatments include a thinning from above, which emulates diameter-limit cutting, a common non-silvicultural practice on private lands.

Example No. 2.—Uneven-age silvicultural studies on the Bartlett Experimental Forest have featured the use of group

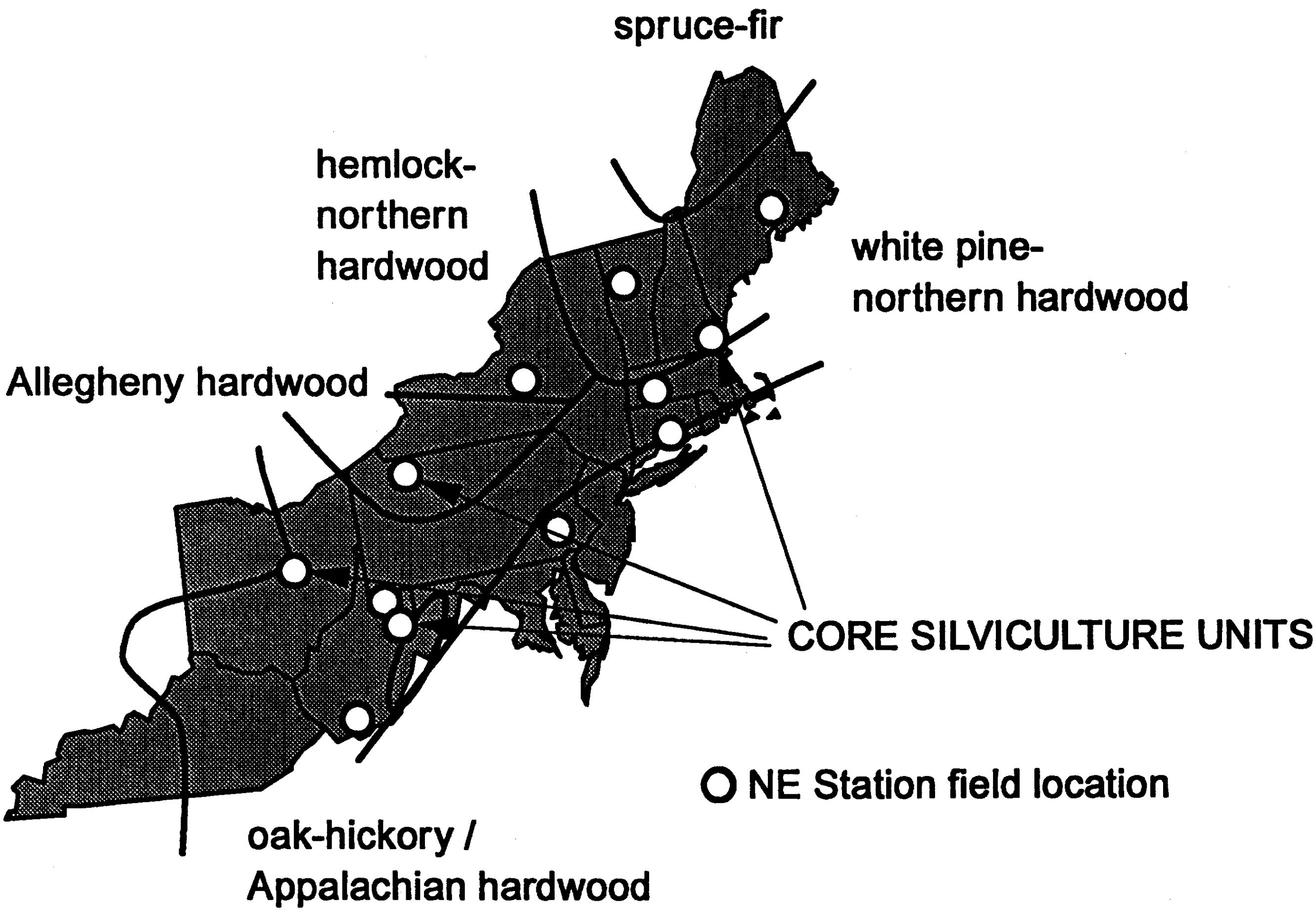

Figure 1.—Location of core silviculture research work units across the Northeastern Forest Experiment Station, with reference to associated major forest types.

selection—the harvesting of trees in small groups as contrasted with single-tree removals. Group selection concentrates the harvesting on groups of mature/overmature trees, produces excellent regeneration in northern hardwood stands, and is acceptable to many NIPF's. Research continues on the effects of a broad range in group size on regeneration, productivity, and wildlife habitat, and the influence of site or landtype on group-selection dynamics (McClure and Lee 1992; Leak and Filip 1977).

Example No. 3.—Regenerating oaks on mesic sites is a widespread problem for forest managers throughout the eastern deciduous forest biome. Regeneration methods continue to be evaluated (Schuler and Miller 1995) and refined to achieve oak regeneration objectives (Schlesinger and others 1993, Loftis 1990). The Station is starting an oak regeneration initiative to coordinate efforts in this area. It will be concentrated within the oak-dominated forest types of Pennsylvania, Ohio, West Virginia, and Maryland. A portion of this area has suffered regeneration failures due to severe gypsy moth mortality, lack of advanced regeneration, overbrowsing by deer, invasion by exotic plants, other insects and pathogens, fire control, and lack of seed sources. We will develop techniques for rehabilitating these sites to restore oak-dominated forest ecosystems. Ecological site classification and other tools will continue to be used to help in the development of regeneration treatments. Natural (see Examples No. 4 and 5) and artificial (see Example No. 6) regeneration techniques will be developed. Cleanings and other precommercial silvicultural treatments will be investigated in relation to maintaining oak presence once regenerated (see Example No. 14). The goal of the research initiative is to develop guidelines for use in Eastern U.S. forests; therefore, treatments will need to be simple and cost-effective for them to be considered and implemented by NIPF landowners.

Example No. 4.—There is wide recognition that oaks are highly fire adapted, and that fire played a major role in the ecology of oak forests in the past, particularly in promoting the dominance of oak in regeneration layers. Fire has been absent from most of the oak-hickory type for most of this century. A study was recently initiated to determine the ecological response of mixed-oak communities in southern Ohio to prescribed underburning under fall and spring fire regimes. In addition to measuring tree regeneration response, the study aims to develop silvicultural tools for restoring the structure (fire adapted flora) and function to mixed-oak forests.

Example No. 5.—Regeneration practices that promote two-age stand structures have been applied as a viable alternative to clearcutting on national forests, state forests, and private forests in many eastern states. Similar to clearcutting, two-age regeneration treatments provide adequate light and seedbed conditions for the germination and development of numerous desirable hardwood species (Miller and Schuler 1995). However, this innovative silvicultural practice entails leaving a certain number of mature overstory trees per unit area in perpetuity to meet additional management objectives, particularly aesthetics and wildlife habitat. New research is needed to determine the growth patterns (for example, crown expansion rates) of the residual trees and the long-term effects of such factors on the developing reproduction. One such study is aimed at defining improved methods for increasing the proportion of oak regeneration that develops before and after two-age cuts are applied. This work includes shelterwood treatments to promote more competitive advance oak reproduction before two-age cuts and cleaning treatments to sustain saplings once they are established.

Example No. 6.—Natural regeneration methods for oak may require a lengthy period of time. An alternative regeneration technique being considered is the use of plastic tree shelters to protect seedlings from deer browsing and to stimulate juvenile height growth (Schuler and Miller 1996, Smith 1993). Tree shelters were developed in Europe and have been undergoing field trials since the late 1980's in the Eastern U.S. Station personnel have been leaders in determining the utility of tree shelters for differing silvicultural practices and land ownership preferences (Walters 1993, Smith 1993). Ongoing studies on both the Allegheny and Monongahela National Forest are evaluating the operational utility of shelters. Several long-term continuously monitored tree shelter studies are located on the Fernow Experimental Forest in West Virginia. The results from these efforts have led to the development of guidelines for tree-shelter use in establishing mesic-site oaks (Schuler and Miller 1996, Smith 1993). Continued research in this area is attempting to identify silvicultural treatments needed to maintain successfully established oak seedlings within the upper canopy stratum during the early stem exclusion stage.

Multiple Tangible Output Initiative

Historically, silvicultural research has focused on regeneration and wood production at the stand-level. Within the Station, long-term studies are being adapted to include additional non-commodity outputs within a hierarchy of spatial scales. And new studies are being installed to relate silvicultural practice to wildlife and wildlife habitat, aesthetics, old-growth (Nelson et al. 1997, this volume), forest health, riparian values, and the interactions among all these values.

Example No. 7.—In 1992, a 10-year research study was begun to determine the impacts of glyphosate and sulfometuron methyl on plants and wildlife in Allegheny hardwoods. The featured dependent variables in the study are herbaceous plants, small mammals, amphibians and songbirds. This research focuses on herbicide-shelterwood treatments, while a related administrative study focuses on the impact of herbicides in group selection treatments.

Example No. 8.—Research on the implications of two-age silviculture as an alternative regeneration method was initiated by Station scientists and land managers on the Monongahela National Forest in 1979 (Smith et al. 1989). Continuing silvicultural research is in progress to determine how the residual trees (density, structure, and species composition) affect the regeneration of eastern hardwoods and the production of multiple forest benefits such as aesthetics, species diversity, high-quality wood products, and habitat for wildlife species. For example, songbird density and nest success 10 years after clearcutting were compared with that observed 10 years after two-age cuts (Miller et al. 1995). Overall songbird density was greater in the two-aged stands, primarily as a result of the more diverse vertical structure of the residual stand. Other examples include comparisons of the aesthetics of two-age to other silvicultural treatments (Ping and Hollenhorst 1993) and evaluations of the immediate and long-term product market options of two-age systems compared to alternative management systems (Miller and Baumgras 1994) associated with perpetual two-age structures. As the application of two-age systems becomes more common, long-term data and experience gained from studying the early stage of two-age systems will play a vital role in answering new questions.

Example No. 9.—On the Kane Experimental Forest on the eastern edge of the Allegheny National Forest, a well-designed cleaning study was established in young Allegheny hardwoods in 1936. During the winter of 1996-97, we re-opened this study and remeasured tree and stand growth and development, including quality, to meet contemporary needs for information on young stand silviculture. Similar long-term studies of cleaning and weeding are being analyzed across the Station for northern hardwoods, transition oak, and oak-hickory.

Example No. 10.—Since the early 1950's, Station scientists have been evaluating effects of an array of silvicultural treatments on composition and structure of mixed northern conifers at the Penobscot Experimental Forest in east-central Maine. Even-age treatments in this replicated experiment include clearcutting and shelterwood. Selection stands in this study are the only examples of uneven-age silviculture in northern conifers in the Eastern U.S. Treatments also include diameter-limit cutting which, although not part of a silvicultural system, is a common practice in the region. Initial goals of the study were to determine how best to manage for financial returns and to determine if silviculture could reduce impacts of periodic spruce-budworm epidemics. As the treated stands developed, they also have been used to evaluate silvicultural effects on soils, wildlife habitat, insect diversity, coarse woody debris, and individual tree and stand growth efficiency.

Two recent publications demonstrate the value of this experiment to land managers. A financial analysis by Sendak and others (1996) indicated that the managed forest value is greater under selection silviculture than under even-age systems. In an evaluation of the effects of intensity and frequency of harvesting on natural regeneration, Brissette (1996) showed that regardless of treatment, regeneration is prolific and dominated by balsam fir, hemlock, and spruce. However, a number of other species are well represented, providing managers with several options to meet future objectives. The value of these two analyses was substantially enhanced because of long-term databases available. This study has produced a diversity of stands with a range of species composition and structure, and interest in it for overlaying additional studies continues to grow.

Example No. 11.—Thinning regimes for Allegheny hardwoods were first developed in the mid-1970's using short-term field study results and computer simulations (Roach, 1977) and refined with longer term research (Marquis 1986, 1994; Ernst 1987; Marquis and Ernst 1991; Nowak 1996, 1997; Nowak and Marquis 1997). Many long-term field experiments on thinning are just now entering the end of the first cutting cycle, about 15 to 20 years after the initial cut. Thinning guidelines will continue to be refined using long-term results of these guidelines. A classic set of response variables will be featured in these studies, including wood production, tree stem quality, and understory vegetation response to changes in stand density, structure and species composition. A mechanistic approach will be used, for example, individual tree response will be related to crown architecture (see Nowak 1996) and other life history characteristics, and stand response will be related to plant succession and stage of stand development.

Example No. 12.—Silvicultural treatments can minimize gypsy moth damage to host hardwood stands. Decision charts were developed that match the proper prescription to existing stand and insect population conditions based on ecological and silvicultural information on forest-gypsy moth interactions (Gottschalk 1993). Some of these silvicultural treatments are currently being tested in several large research and demonstration studies with encouraging preliminary results. Use of silviculture to manage gypsy moth effects gives the forest manager tools other than chemical or biological insecticides for developing integrated pest management programs. Prescriptions for treatments take several approaches: reducing stand susceptibility and the probability of defoliation by changing species composition and gypsy moth habitat features; reducing stand vulnerability and the probability of mortality by removing trees most likely to die after defoliation (Gottschalk and MacFarlane 1993) and leaving trees more likely to survive and increase in vigor including regenerating stands in some cases; and treating stands after defoliation by salvage of dead trees, thinning of live trees to increase vigor and regenerating understocked stands.

Example No. 13.—Thirty-year results from a precommercial thinning study on the Bartlett Experimental Forest in a 25-year-old stand showed that fairly drastic treatments (for example, release of 400 crop trees/acre on all sides or complete removal of all weed trees) produced modest increases in tree diameter but had little effect on the species composition or structure of the stand (Leak and Smith, in press; Leak and Solomon, in press). Monitoring continues on the long-term effects of early thinning on quality development.

Example No. 14.—Thinning entails providing individual trees with added growing space by releasing their crowns, that is, removing adjacent trees whose crowns touch those of desirable crop trees. Such crown-release treatments have been studied in 7- to 80-year-old stands in the central Appalachian region since the 1960's. Results of these trials, formerly published in numerous separate reports, were synthesized and combined with new information from more recent studies (Miller, in press). Crown growing space, derived from the proportion of crown perimeter free-to-grow and distance to adjacent competing trees, is a significant independent variable that affects growth response. Crown growing space has a positive effect on d.b.h. growth and crown expansion and a negative effect on height growth and length of clear stem. The impact of crown growing space diminishes with tree age, though significant increases in d.b.h. growth were observed for 80-year-old trees. Additional research is needed to define how crown growing space affects other responses such as resistance to disease, longevity, and seed production. Applications of crown release treatments might be useful in sustaining certain individual trees for wildlife habitat and/or accelerating the development of certain stand attributes such as old-growth that are defined, in part, by tree size.

Example No. 15.—Truly integrated management of forest resources requires linking our understanding of wildlife habitat requirements to measured vegetative conditions. Using data from a series of operational- and research-scale study stands, scientists are refining thresholds for wildlife habitat in managed stands. In the short term, they will produce assessment tools for NED, a family of decision support software tools under development by the Station. Ultimately, researchers will develop silvicultural prescriptions to maintain, improve, or create habitat for specific wildlife.

Example No. 16.—Awareness of the importance of dead wood structures in forests has increased. The role of dead wood as habitat for wildlife and as foundation for many important processes such as regeneration and nutrient cycling is being investigated in many work units.

Intangible Outcome Initiative

The focus of silvicultural research is shifting from single and multiple value objectives to relationships among silvicultural activities and landscape-scale ecological balances, biological diversity, commodity production and other single forest value needs. Challenges for the future include expanding our mindsets from stands to landscapes, and from tangible, measurable outputs to intangible values that are more difficult to measure.

Example No. 17.—For more than 50 years we have recognized that deer impact is too high for many forest values on the Allegheny Plateau (Redding 1995), and that silviculture may be used to mitigate deer impact by manipulating deer forage-density-impact relations (Hough

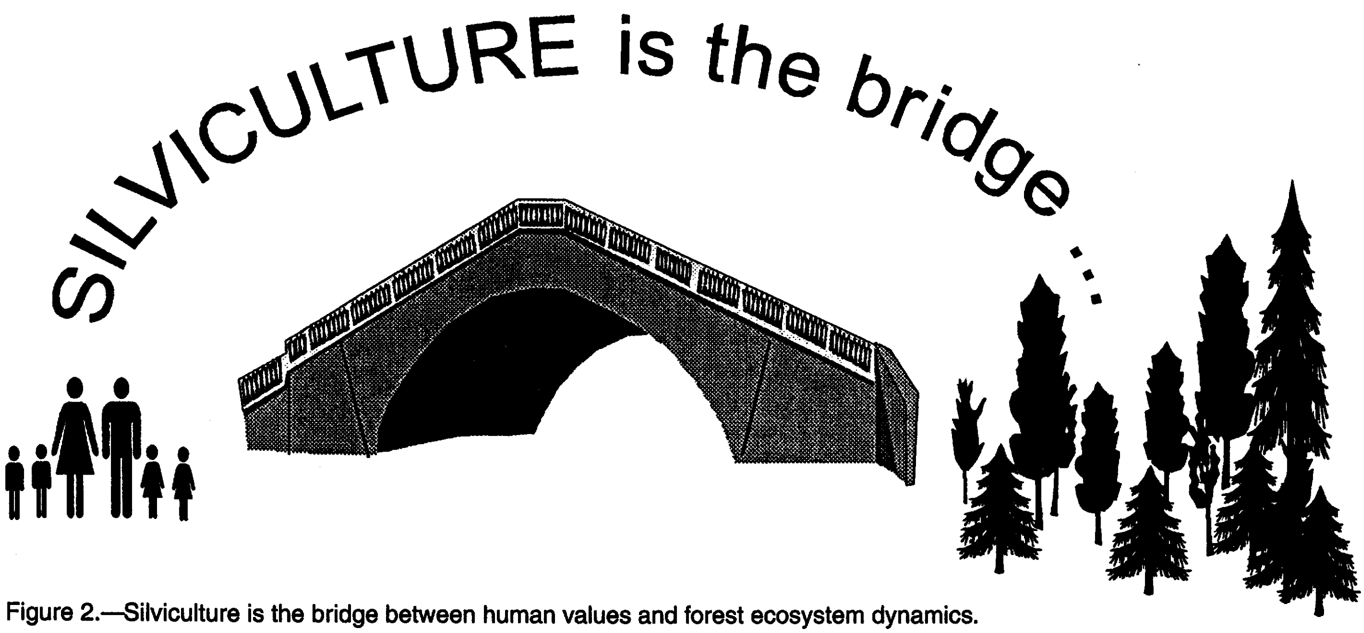

Figure 2.—Silviculture is the bridge between human values and forest ecosystem dynamics.

1953). Despite the long-term recognition of deer problems and attendant solution possible with silviculture, it is only with contemporary research (Stout et al. 1996; Stout and Lawrence 1996) that guidelines are being developed to specifically manage forest harvest areas and their spatial patterns to minimize the impacts of deer browsing on forest regeneration, wildlife habitat, and biological diversity.

Example No. 18.—Silvicultural research is moving from a preoccupation with stand-level responses to evaluation of silvicultural effects on species, structure, and wildlife habitat at the landscape level. Scientists recently completed an analysis of 60 years of data on the cumulative effects of management and natural disturbance (disease and wind damage) on species and structure across the Bartlett Experimental Forest. This analysis showed that natural succession (eastern hemlock dynamics particularly) was the primary influential factor—emphasizing the resilience of New England forests and their resilience to exogenous disturbance (Leak and Smith 1996). Similar examinations of long-term silviculture effects across ecosystems and landscapes are possible throughout the Station.

Example No. 19.—The effects of forest cutting on residual stand conditions have been examined across the State of Pennsylvania in two recent studies (McWilliams et al. 1995; Finley and Jones, in press; Nowak, in press). Future work should include more refined analysis of regeneration patterns across the Commonwealth and implications for sustainability, health, and productivity.

WHAT ARE THE LINKS TO THE OTHER EIGHT RESEARCH THEMES IN ROADMAP?

Silviculture is the bridge between human values and forest ecosystem dynamics (Fig. 2). Research provides the tools for managers to build that bridge.

As an integrating discipline, silvicultural research is viewed as the bridge between all of the more basic research themes (such as Basic Processes and Disturbance and Ecosystem Dynamics) and the social and economic dimension themes (such as Social and Economic Dimensions, and Forest Products, Production, and Use). This research is parallel to, and must be coordinated with, other management research themes (such as Inventory and Monitoring, Managing Forest Health, and Wildlife) and the other information integrating theme—Systems Modeling and Integration. The silvicultural theme integrates and translates more basic science information and information about societal needs into context for methods, guidelines, and models for managing forests. The approach for silvicultural and resource management research is focused on looking at the effects of manipulating vegetative communities. The nature of manipulation and variables for study are based on results from the more basic themes and customer needs. Study goals are built from social and human dimensions research. Research results from the themes in ROADMAP are the foundations and provide the biological and social sideboards for silviculture and resource management research and development.

The bridge analogy has been useful in communicating the role of silviculture and silvicultural research. It stresses the contribution of silvicultural research—developing practical options for sustainable management of forests—while building a critical relationship of silviculture to the other disciplines. As the other disciplines produce new knowledge, silvicultural researchers are poised to fashion that new information into useful and tangible resource management guidelines.

THIS IS A WORK IN PROGRESS ...

The key to a successful future role of silvicultural research is continued communication, continued redefinition of what silviculture research is and can be, and continued growth in the relationship between silviculture and the other disciplines. A critical part of that communication is feedback from our stakeholders. We invite constructive criticism of this paper so that we can incorporate new ideas into our growing portrayal of silvicultural research in the Station.

LITERATURE CITED

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

Ernst, R. L. 1987. **Growth and yield following thinning in mixed species Allegheny hardwood stands.** In: Nyland, R. D., ed., Managing northern hardwoods: proceedings of a silvicultural symposium; 1986 June 23-25; Syracuse, NY. Fac. For. Misc. Publ. No. 13 (ESF 87-002) 211-222.Syracuse, NY: S.U.N.Y. Coll. of Env. Sci. and For.: 211-222.

Finley, J. C.; Jones, S. B. (In press). **Northern Appalachian forests: How are we doing?** In: Forest sustainability: what's it all about?: proceedings 1997 Penn State Forest Resources Issues Conference; 1997 March 26-27; University Park, PA. The Pennsylvania State University; State College, PA.

Gottschalk, K. W. 1993. **Silvicultural guidelines for forest stands threatened by the gypsy moth.** Gen. Tech. Rep. NE-171. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 49 p.

Gottschalk, K. W.; MacFarlane, W. R. 1993. **Photographic guide to crown condition of oaks: use for gypsy moth silvicultural treatments.** Gen. Tech. Rep. NE-168. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Hough, A. F. 1953. **Preliminary recommendations for the management of black cherry on the northern Allegheny Plateau.** Journal of Forestry. 51: 184-188.

Leak, W. B.; Filip, S. M. 1977. **Thirty-eight years of group selection in New England northern hardwoods.** Journal of Forestry. 75: 641-643.

Leak, W. B.; Smith, M. L. 1996. **Sixty years of management and natural disturbance in a New England forested landscape.** Forest Ecology and Management. 81: 63-73.

Leak, W. B.; Smith, M. L. (In press). **Long-term species and structural changes after cleaning young even-aged northern hardwoods in New Hampshire, USA.** Forest Ecology and Management.

Leak, W. B.; Solomon, D. S. (In press). **Long-term growth of crop trees after release in northern hardwoods.** Northern Journal of Applied Forestry.

Loftis, D. L. 1990. **A shelterwood method for regenerating red oak in the southern Appalachians.** Forest Science. 36(4): 917-929.

Marquis, D. A. 1986. **Thinning Allegheny hardwood pole and small sawtimber stands.** In: Smith, H. C.; Eye, M. E., eds. Guidelines for managing immature Appalachian hardwood stands: workshop proceedings; 1986 May 28-30; Morgantown, WV. SAF Publ. 86-02. Morgantown, WV: West Virginia University Books: 68-84.

Marquis, D. A. 1994. **Thinning principles and practices: control of stand density, structure, and species composition during thinning in hardwood stands in the Alleghenies.** In: Marquis, D. A., ed. Quantitative silviculture for hardwood forests of the Alleghenies. Gen. Tech. Rep. NE-183. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 247-287.

Marquis, D. A.; Ernst, R. L.. 1991. **The effects of stand structure after thinning on the growth of an Allegheny hardwood stand.** Forest Science. 37: 1182-1200.

McClure, J. W.; Lee, T. D. 1992. **Small-scale disturbance in a northern hardwood forest: effects on tree species abundance and distribution.** Canadian Journal of Forest Research. 23: 1347-1360.

McWilliams, W. H.; Stout, S. L.; Bowersox, T. W.; McCormick, L. H. 1995. **Adequacy of advance tree-seedling regeneration in Pennsylvania's forests.** Northern Journal of Applied Forestry. 12: 187-191.

Miller, G. W. (In press). **Effect of crown growing space and age on the growth of northern red oak.** In: Advances in research in intermediate oak stands: proceedings of IUFRO Conference; 1997 27-30 July; Freiburg, Germany.

Miller, G. W.; Baumgras, J. E. 1994. **Efficient silvicultural practices for eastern hardwood management.** In: Opportunities for the hardwood industry to address environmental challenges. proceedings of the 22nd Annual Hardwood Symposium of the Hardwood Development Council; 1994 12-15 May; Cashiers, NC. Memphis, TN: Hardwood Research Council: 23-35.

Miller, G. W.; Schuler, T. M. 1995. **Development and quality of reproduction in two-age central Appalachian hardwoods—10-year results.** In: Gottschalk, K. W.; Fosbroke, S.L.C., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 364-374.

Miller, G. W.; Wood, P. B.; Nichols, J. V. 1995. **Two-age silviculture: an innovative tool for enhancing species diversity and vertical structure in Appalachian hardwoods.** In: Eskew, L. G., comp. Forest health through silviculture: proceedings of the 1995 National Silviculture

Workshop. Gen. Tech. Rep. RM-67. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest Experiment Station: 175-182.

Nelson, B.; Nowak, C.; Reitz, S.; deCalesta, D.; Wingate, S. 1997. **Communicating old-growth forest management on the Allegheny National Forest.** In: Proceedings of the 1997 National Silviculture Workshop; 1997.

Nowak, C. A. 1996. **Wood volume increment in thinned, 50- to 55-year-old, mixed species Allegheny hardwoods.** Canadian Journal of Forest Research. 26: 819-835.

Nowak, C. A. 1997. **Developing combined crop tree and area-wide marking guides for hardwood forests of the Alleghenies.** Northern Journal of Applied Forestry 14: 99-101.

Nowak, C. A. (In press). **Long-term sustainability: The next forest.** In: Forest sustainability: what's it all about?: proceedings 1997 Penn State Forest Resources Issues Conference; 1997 March 26-27; University Park, PA. The Pennsylvania State University; State College, PA.

Nowak, C. A.; Marquis, D. A. 1997. **Distribution-of-cut guides for thinning in Allegheny hardwoods: A review.** Res. Note NE-362. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Nyland, R. D. 1996. **Silviculture: concepts and application.** New York: McGraw-Hill Companies, Inc., New York. 633 p.

Ping, O.; Hollenhorst, S. 1993. **Managing eastern hardwoods for visual quality.** In: Vander Stoepp, G. A., ed. Proceedings of the 1993 northeastern forest recreation symposium; 1993 April 18-20; Sarasota Springs, NY. Gen. Tech. Rep. NE-185. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 89-93.

Redding, J. 1995. **History of deer population trends and forest cutting on the Allegheny National Forest.** In: Gottschalk, K. W.; Fosbroke, S. L., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 323-328.

Roach, B. A. 1977. **A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings.** Res. Pap. NE-373. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 30 p.

Schlesinger, R. C.; Sander, I. L.; Davidson, K. R. 1993. **Oak regeneration potential increased by shelterwood treatments.** Northern Journal of Applied Forestry. 10: 149-153.

Schuler, T. M.; Miller, G. W. 1995. **Shelterwood treatments fail to establish oak reproduction on mesic forest sites in West Virginia—10-year results.** In: Gottschalk, K. W.; Fosbroke, S. L. C., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 375-387.

Schuler, T. M.; Miller, G. W. 1996. **Guidelines for using tree shelters to regenerate northern red oak.** In: Brissette, J. C., ed. Proceedings of the Tree Shelter Conference; 1995 June 20-22; Harrisburg, PA. Gen. Tech. Rep. NE-221. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 37-45.

Sendak, P. E.; Frank, R. M.; Brissette, J. C. 1996. **Financial analysis of northern conifer stands under various silvicultural treatments.** In: Sustaining forests, sustaining people: proceedings of the 1995 Society of American Foresters Convention; 1996 Oct. 28-Nov. 1; Portland, ME; SAF Publ. 96-01, Bethesda, MD. Society of American Foresters: 368-369.

Smith, H. C. 1993. **Development of red oak seedlings using plastic shelters on hardwood sites in West Virginia.** Res. Pap. NE-672. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Smith, H. C.; Lamson, N. I.; Miller, G. W. 1989. **An aesthetic alternative to clearcutting?** Journal of Forestry. 87: 14-18.

Stout, S. L.; DeCalesta, D. S., and L. deMarco. 1996. **Can silviculture change deer impact?** In: Sustaining forests, sustaining people: proceedings of the 1995 Society of American Foresters convention; 1996 Oct. 28-Nov. 1; Portland, ME. SAF Publ. 96-01. Bethesda, MD: Society of American Foresters: 437-438.

Stout, S. L.; Lawrence, R. 1996. **Deer in Allegheny Plateau forests: learning the lessons of scale.** In: Sustaining forests, sustaining people: proceedings of the 1995 Society of American Foresters convention; 1996 Oct. 28-Nov. 1; Portland, ME. SAF Publ. 96-01. Bethesda, MD: Society of American Foresters: 92-98.

Walters, R. S. 1993. **Protecting red oak seedlings with tree shelters in northwestern Pennsylvania.** Res. Pap. NE-679. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

Yanai, R. D.; Twery, M. J.; Stout, S. L. (In press). **Woody understory response to changes in overstory density: thinning in Allegheny hardwoods.** Forest Ecology and Management.