Communicating the Role of Silviculture in Managing the National Forests

Proceedings of the National Silviculture Workshop

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Warren, Pennsylvania

Foreword

The 1997 National Silviculture Workshop was held in Warren, Pennsylvania, and hosted by the Allegheny National Forest, Region 9, and the Northeastern Forest Experiment Station. This was the latest in a series of biennial workshops started in 1973, in Marquette, Michigan. The theme of this workshop was "Communicating the Role of Silviculture in Managing the National Forests."

The communication theme is especially timely and critical for several reasons. First, the Forest Service has been practicing good silviculture for several decades, but we have not done a good job of communicating that fact to our publics and customers. Second, the skills and capabilities of our silviculturists have often been overlooked both internally and externally. And finally, we need to communicate the importance of developing and following scientifically sound silvicultural practices as we move toward an ecological approach to the management of the national forests.

An excellent field trip to the Allegheny National Forest and the Kane Experimental Forest was hosted by Allegheny National Forest and Northeastern Station personnel. The field trip gave the participants an opportunity to observe and discuss forest research and management activities and how they might be used to demonstrate how silviculture can be used to achieve a variety of desired forest conditions.

The need for silviculturists to communicate their role and the role of silviculture in the current management of national forests is critical. This was discussed in an open forum at the workshop and a team of NFS (National Forest System) and Research people was assigned to address this need and develop a strategy to deal with it.

The Washington Office Forest Management (WO-FM) and the Forest Management Research (WO-FMR) staffs appreciate the efforts of our hosts in Pennsylvania. Special acknowledgment is made to Chris Nowak, Jim Redding, Susan Stout, Wendy Jo Snavley, and Kathy Sweeney, Northeastern Station; Robert White, Steve Wingate, and Lois Demarco, Allegheny National Forest; and Monty Maldonado, Eastern Region, for their leadership and support in planning, arranging, and hosting the workshop. Also commended are the speakers for their excellent presentations; the poster presenters; the moderators who led the sessions; the 130 participants from Research and NFS from all over the country; and the special guests who participated in the workshop.

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Preparing for the Gypsy Moth — Design and Analysis for Stand Management Dorr Run, Wayne National Forest

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Abstract.—As the advancing front of the gypsy moth continues its spread throughout Ohio, silviculturists on the Wayne National Forest are preparing themselves for potential gypsy moth outbreaks in the coming decade. Through a cooperative effort between the Northeastern Forest Experiment Station and Northeastern Area, Forest Health Protection, the Wayne National Forest, Ohio, is utilizing computer models to identify high-risk stands and evaluate the predicted outcome of several management options. The efforts involve the Stand-Damage Model, a portion of the Gypsy Moth Life System Model and GypsES, a decision support system that provides the transport and storage medium for the forest inventory data used in analysis and stand mapping capabilities. The process involves identifying high-risk stands and simulating development of these stands forward from the inventory year to 1997. A series of three simulations were designed to assess the range of possible tree mortality from none, to light, to heavy outbreak scenarios. If a stand contains sufficient growing stock, a simulated pre-salvage thinning was conducted using two alternative criteria. Stands with a relative stand density greater than 70 percent were cut to 60, and stands with relative stand density greater than 90 percent were cut to 80 percent. Results are given in terms of stem counts, basal area, volumes, and present dollar values. Results show the savings that could be expected if outbreaks occur following these silvicultural treatments and help to prioritize treatment schedules. The results will be used in the decisionmaking process, are documented in an Environmental Assessment as a means to inform the public as to the consequences of each proposed alternative, and will be used in the implementation of site-specific management alternatives.

INTRODUCTION

Gypsy moth (*Lymantria dispar* L.) has been spreading from its origin of introduction into North America and is currently established in western Pennsylvania, most of West Virginia, and northeastern Ohio (Liebhold et al. 1997). Gypsy moth is expected to become established in and around the Wayne National Forest in the coming decade: 1998-2007 (Fig. 1). New gypsy moth populations cause significant damage, due in part to the lack of co-establishment of its full natural enemy complex. It is expected that losses will occur in Ohio similar to those found over the past two decades in western Pennsylvania. The part of the Wayne National Forest that is of greatest concern to the forest silvicultural staff is the Dorr Run Area because this area has the highest proportion of high-hazard stands. The Dorr Run Area is located on the Athens Ranger District in Green and Ward Townships, Hocking County, Ohio, in the unglaciated Allegheny Plateau.

Because of the dense stocking, growth has slowed on a large number of trees. Gypsy moths have been trapped at increasing rates in Hocking and surrounding counties for several years. It is expected that gypsy moths could have a serious impact in this area because of the high proportion of oak and other preferred species and the generally over-stocked and low-vigor conditions that exist in many of the stands. Some mortality of oak trees is beginning to occur from shoestring root rot (*Armillaria mellea*) and twolined chestnut borer (*Agrilus bilineatus*).

Land management objectives for the Dorr Run Project Area are described in the Wayne National Forest Land and Resource Management Plan (USDA Forest Service 1988[2]). The objectives for this management area are to maintain wildlife habitat diversity, provide high-quality hardwoods on a sustained yield basis, provide various dispersed recreation opportunities, and provide off-road vehicle use.

Because of the foregoing forest health conditions and to implement the Land and Resource Management Plan, the Dorr Run Area was selected for analysis and development of vegetation management proposals. The purpose and need of the Dorr Run project is to maintain and improve forest health. Thomas (1996)[3] characterized healthy forests as "...those where biotic and abiotic influences do not seriously threaten resource management objectives, now or in the future, nor do resource management activities seriously threaten sustainability or biodiversity."

This project was a joint effort among all three branches of the USDA Forest Service. The Wayne National Forest was interested in determining what damage could occur from gypsy moth defoliation. There was interest in using the results of the Gypsy Moth Stand-Damage Model in an environmental analysis to explain to the public what the potential damage could be from gypsy moth defoliation for each of the alternatives. In addition, the data produced for individual stands would be valuable in prescribing silvicultural treatments and developing marking guidelines for specific stands. Research was interested in this project to demonstrate new modelling technology and to investigate a

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[2]U. S. Department of Agriculture, Forest Service. 1988. Land and Resource Management Plan: Wayne National Forest. As amended. Wayne National Forest, 219 Columbus Road, Athens, OH 45701-1399.

[3]Thomas, Jerome. 1996. 3400 Memo of 1/25/96 on Southern Tier Forest Health Conference Call Summary. USDA, Forest Service, Eastern Region. 310 W. Wisconsin Ave., Rm. 500, Milwaukee, WI 53203.

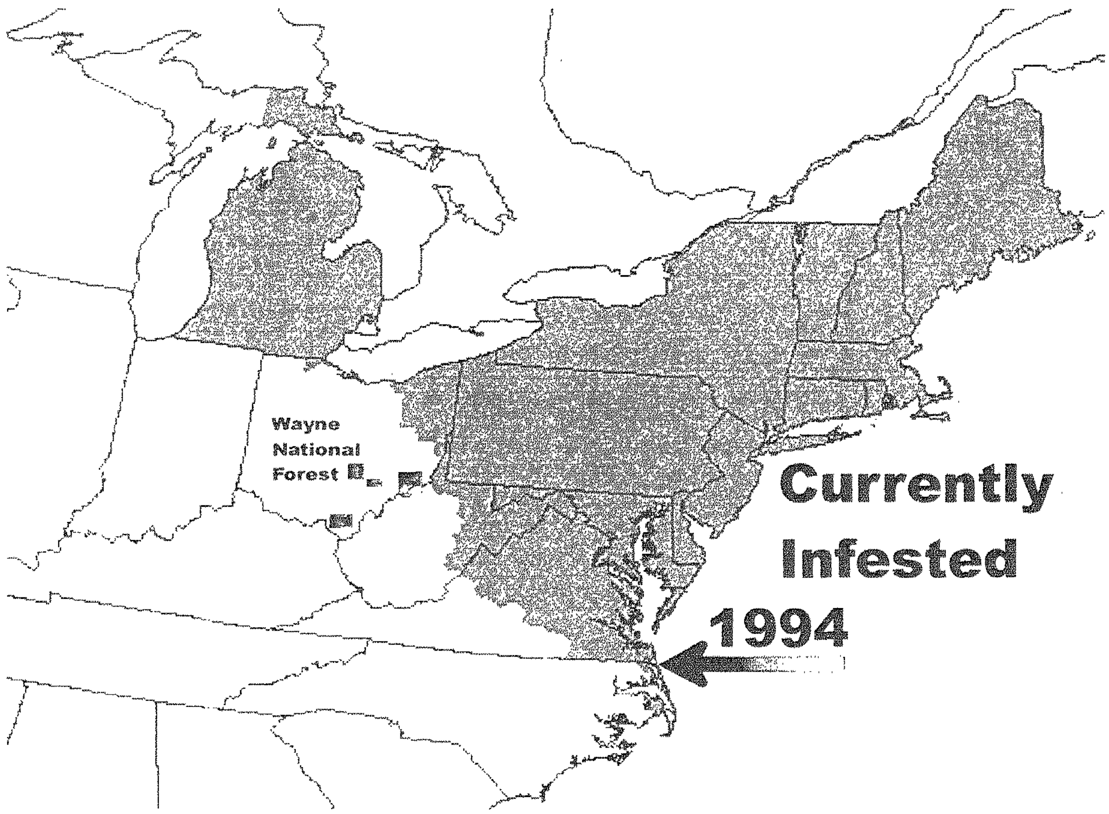

Figure 1.—Area currently infested with gypsy moth, as of 1994, and the location of the Wayne National Forest in southeastern Ohio.

significant problem using current inventory data from the Wayne National Forest. Moreover, there is a need to constantly validate models. We will be able to compare these predicted results to later actual management practices and defoliation effects, extending our knowledge of the geographic and ecological range of model applicability. State and Private Forestry's role is to coordinate between national forests and the research branches of the Forest Service, and to assist in the collection, management, and transfer of data used to support forest health assessments. Forest Health Protection's mission is to disseminate information based upon research that can be utilized not only in the management of national forests, but also on state forests and private lands.

The Environmental Assessment for the Dorr Run Project Area states that the purpose of silvicultural treatments is to "restore vigor, shape species composition, and work toward the establishment of the next forest" (USDA Forest Service 1997[4]). Five alternatives were developed and analyzed in the environmental analysis to determined how well each alternative achieved the purpose and to analyze the effects on the environment of each alternative. The analysis in this paper was utilized in documenting the environmental consequences of each of the alternatives. Silvicultural treatments were proposed to reduce damage, such as mortality or loss of mast production, by removing highly vulnerable trees before they are defoliated and die.

METHODS

Within the Dorr Run Project Area there are 5,183 acres of national forest land and approximately 3,200 acres of private land. Thirteen forest types have been identified, and six of these are oak-hickory forest types that total 3,231 acres or 62 percent of national forest land within the project area. In addition there are 39 acres of aspen stands. Oaks and aspen are preferred food species of the gypsy moth (Liebhold et al. 1995). The remaining acreage consists of a variety of non-oak hardwoods with a small amount of pine. Most of the forest in this area is greater than 60 years old, and 91 percent of this is in the oak-hickory forest types. Site Index (50-year black oak, Carmean et al. 1989) averaged 73.6 over the stands included in the initial sample and ranged from 65 to 94, with mean equal to 73 across the 24 stands used in the final analysis.

In the Dorr Run Area, oak-hickory stands are found on the more xeric sites located on ridgetops, middle to upper place

[4]U.S. Department of Agriculture, Forest Service. 1997. Environmental Assessment: Dorr Run, Hocking County, Ohio, Athens Ranger District, Wayne National Forest, March 1997. Wayne National Forest, 219 Columbus Road, Athens, OH 45701-1399. 98 p.

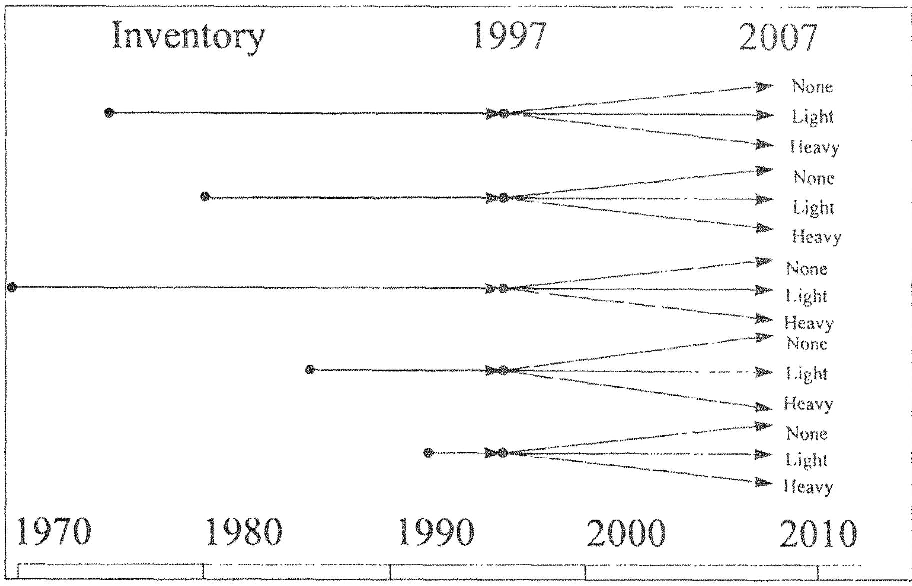

Figure 2.—Process of simulations: inventories for each stand are grown forward to 1997; if silvicultural prescriptions are to be simulated, that happens next; finally the three 10-year simulation scenarios (none, light, and heavy outbreak) ending in 2007 are executed.

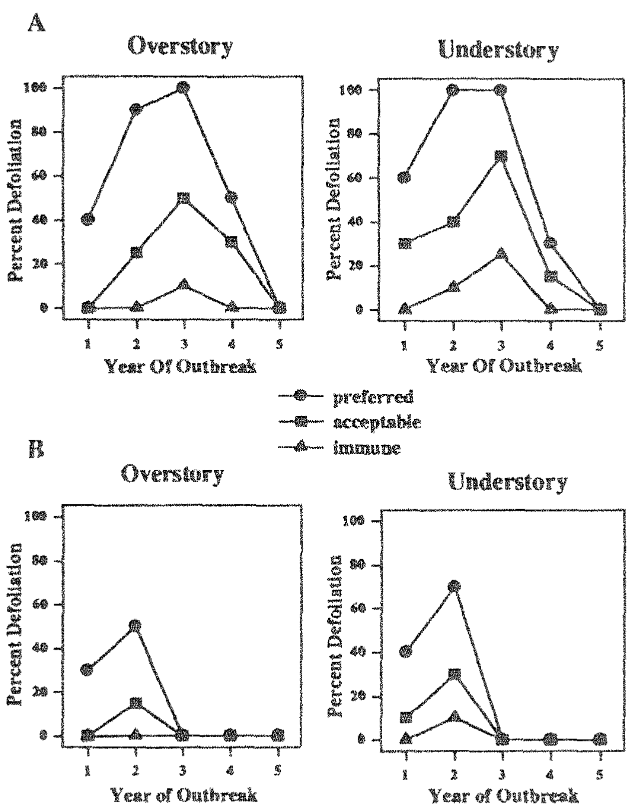

Figure 3.—A. Heavy outbreak defoliation intensities in the overstory and understory for 5 years. Gypsy moth host tree species determines feeding preference class. Each simulation repeats this 5-year sequence twice over the 10-year simulation. B. Light outbreak defoliation intensities.

slopes on southeast to northwest aspects, and upper slopes on the northeast aspect. The majority of this area is densely stocked.

Analysis was based upon compartment examination data that are routinely collected by Wayne National Forest personnel. Individual tree data were collected on 10 BAF variable-radius plots. The forest types used in the analysis were [1] black oak—scarlet oak—hickory; [2] white oak; [3] yellow-poplar—white oak group—red oak group; and [4] mixed oak. Chestnut oak forest type and northern red oak forest type were not used because these types occurred on too few stands.

To assess the possible damage caused by future gypsy moth outbreaks in the Dorr Run Area we used a sample of 38 stands that were well distributed across six compartments and the four principal oak-hickory forest types that the gypsy moth is known to find most preferable, representing both the spatial mixture and the ecological range of potential impacts. The available inventory was categorize to compartment and forest type; a balanced random sample was chosen from within this stratification. We investigated potential losses by producing a series of stand growth and defoliation scenarios using the Gypsy Moth Stand-Damage Model (Colbert and Racin 1995, Colbert and Sheehan 1995). First, the model was used to grow all tree data from previous inventories forward through 1996 to represent the current condition of each stand. Growth scenarios, each a 10-year projection, were then constructed to estimate potential tree mortality (Fig. 2). Simulations were run with and without defoliation and following selected silvicultural activities simulated to take in 1997. Figure 3 shows the heavy and light defoliation scenarios that were used in this analysis. These scenarios are the same duration and intensity as those developed for loss assessments in the National Gypsy Moth Environmental Impact Statement (Northeastern Area, State and Private Forestry 1995). Each decade simulation consisted of two 5-year outbreak cycles. The amount of defoliation to a particular tree depended upon its location in the stand canopy and the feeding preference of gypsy moth to that tree species (Liebhold et al. 1995).

Table 1.—Stumpage price in 1997 dollars per thousand board-feet (Source: 1995 Ironton R. D. sales, Timber Sales Staff, Wayne National Forest).

Common name	Scientific name	Price
		Dollars
White Ash	*Fraxinus americana* L.	240.00
Black Walnut	*Juglans nigra* L.	240.00
Yellow Poplar	*Liriodendron tulipifera* L.	60.00
Black Cherry	*Prunus serotina* Ehrh.	240.00
White Oak	*Quercus alba* L.	150.00
Scarlet Oak	*Quercus coccinea* Muenchh.	55.00
Chestnut Oak	*Quercus prinus* L.	55.00
Red Oak	*Quercus rubra* L.	195.00
Black Oak	*Quercus velutina* Lam.	195.00

Under each alternative a no-defoliation scenario was used as the control to base the effects of defoliation upon each variable, summarized to the stand level in 2007, at the end of the simulation. Stem count, relative density (Stout and Nyland 1986), basal area, board-foot volume, and net present value were used to characterize each stand. To calculate the potential dollar losses, local stumpage values ($/MBF) for the most commercially important species were determined (Table 1). All other species were set to $35.00/MBF as the default 1997 value. Net present values (1997) for final 2007 stumpages were calculated using a 5 percent discount rate.

The two silvicultural alternatives chosen for this study consist of prescribing three parameters, the second of which depends upon the stands relative density in 1997. First, all stems less than 6 inches are removed. Second, the residual stand density is set either to 60 percent or to 80 percent of full stocking, if the 1997 relative density is above 70 percent or 90 percent, respectively. Finally, the removals are weighted toward higher removal of smaller stems, 20 percent more is removed from the smallest diameter class than is removed from the largest diameter class present and this weight is scaled down linearly from the smallest to the largest diameter class.

The GypsES Decision Support System is an expert system shell and GIS to support management of gypsy moth problems (Gottschalk et al. 1996). Besides providing access to the tree data organized in an efficiently linked database, this system provides access to stand level information, which links the models directly to the database for setting initial conditions and providing an efficient means to compile the 18 tables from each simulation of each stand for each treatment into compact files for further analysis. The menu-based selection of particular stands and system's ability to recall the structure and format designations for simulation outputs made the operation of repeated simulations much more efficient than the process would have been otherwise.

The entries provided in the summary tables were obtained as follows: first the totals across all trees in each stand simulation were calculated, then the loss in each stand was calculated as the difference between the outbreak and the no-outbreak totals. For example, the basal area is calculated and summed for all trees in each stand for each of the three simulations (no defoliation, heavy outbreak, and light outbreak), then the difference is calculated on a stand-by-stand basis (heavy minus none and light minus none), and finally the mean of these differences in basal area for each stand is presented here, as the average loss in basal area. The range of variability among the stands used in this study is also reported.

RESULTS

Three sets of alternative management scenarios were investigated: no action, light presalvage thinning to 80 percent relative stocking, and presalvage thinning to 60 percent relative stocking (B-line). The no-action alternative serves both as one alternative and as the basis for comparing effectiveness of alternate possible actions.

No Action Alternative

To ascertain how silvicultural manipulations aimed to reduce potential gypsy moth impacts could improve these stands, base-line information on the range of potential impacts is needed. The first step in this process is to simulate growth of the inventory data to the current year (1997) to provide equivalent starting points. Then each stand was projected forward from 1997 to 2007 three times: a) to estimate stand conditions in the absence of gypsy moth; b) to assess impacts of defoliation under the light outbreak scenario; and c) under the heavy outbreak scenario. These data provide the no-action alternative and bounds for assessing the effectiveness of silvicultural alternatives. By summarizing the means and extremes across these stands, we obtain the most probable boundary conditions and the basis for measuring management effects. Table 2 provides estimates of these conditions on a per acre basis.

First note that these ranges are assessed independently within each column. That is, the stand that has the smallest number of trees lost may not be the same stand that has the smallest stocking reduction, and both of these may be different from the stand with the smallest basal area loss. In this and following tables, the losses provided are due to defoliation of the residual stand following treatment and do

Table 2.—Future stand conditions following heavy and light outbreaks—losses calculated from the results of simulations on 38 stands.

Stand category	Trees lost	Stocking reduction	Basal area lost	Volume lost
	Trees/acre	Percentage	ft²/acre	MBF/acre
		Heavy Outbreak		
Average	55.9	45.0	52.0	3.0
Best	[44.0]	19.0	19.5	0.7
Worst	383.0	79.0	84.1	5.1
		Light Outbreak		
Average	19.5	6.8	7.7	0.4
Best	0.0	1.0	1.5	0.0
Worst	179.0	21.0	22.3	1.5

Note: the brackets indicate a net gain rather than a loss.

Table 3.—Losses due to defoliation calculated for the 24 stands that qualify for both presalvage treatments (no presalvage thinning done).

Stand category	— Trees lost — All	0-6	6+	Stocking reduction	Basal area lost	Volume lost
	Trees/acre			Percentage	ft²/acre	MBF/acre
				Heavy Outbreak		
Average	69.1	13.6	55.5	55.4	62.2	3.8
Best	[22.0]	[64.0]	27.0	35.0	41.2	2.4
Worst	383.0	345.0	93.0	79.0	84.1	5.1
				Light Outbreak		
Average	21.4	10.6	10.8	9.3	10.4	0.6
Best	2.0	[11.0]	1.0	2.0	2.9	0.1
Worst	179.0	177.0	24.0	21.0	22.3	1.5

Note: the brackets indicate a net gain rather than a loss.

not include the treatments themselves. These estimates provide a view of the possible range of outcomes in susceptible stands as gypsy moth becomes established in the Dorr Run area. Losses of basal area can be expected to range from a low of 20 percent to more than 80 percent in stands heavily dominated by preferred host species, with average losses per acre over the entire area expected to be above 50 square feet of basal area and nearly 3,000 board-feet per acre.

Regeneration was included in these simulations. In the "Trees Lost" column, the loss of trees includes the compensation by ingrowth predictions. Understanding these differences requires some careful interpretation and detailed review however, because replacement trees are often a different species from those lost. Because defoliation and any subsequent tree mortality will inhibit both mast production and stump sprouting, new trees will likely be species not favored by the gypsy moth or species that produce light seeds that can be carried into a stand from surrounding areas. Even as the number of trees increases in a few stands, these new trees are very small and represent natural regeneration. Although tree counts may decline minimally or increase slightly, stocking (a measure of the trees ability to fully occupy the growing space) is reduced significantly. Closely paralleling stocking, the changes in basal area better reflect the losses of the larger trees. The changes in volume per acre (measured here in thousands of board-feet [MBF]) indicate that tree values are significant. Based on market prices as of December 1996, losses may run as high as $381.00/acre from severe outbreaks with an average loss of $245.10/acre.

To permit direct contrasts between silvicultural prescriptions and no management, we again summarize only stands that will qualify for all management prescriptions (Table 3). To qualify for thinning to 80 percent relative stocking, a stand is required to be at least 90 percent fully stocked in 1997. In the Dorr Run Area, 24 stands meet that criteria. These more heavily stocked stands also tend to show higher average losses.

To assist in review of these data, we provide the mean and range for trees lost in three classes: [1] total stems count (all) [2] the small trees (less than 6 inches), and [3] large trees (6 inches and greater). Comparing Tables 2 and 3, one can see that the stands with lower relative stocking levels (the 14 stands dropped) would be affected less by defoliation. In these heavily stocked stands, expected losses will be 20 percent higher than the general average and volume losses are expected to increase more than 25 percent to nearly 4,000 board-feet per acre. This demonstrates that the potential benefits of silvicultural treatment can be substantial.

Presalvage Treatment Alternatives

Silvicultural treatment, in which the most susceptible trees were removed, provides growing space to permit the residual stand to become healthier and more resistant to defoliation as growth rates increase. In the two presalvage treatments considered in this analysis, we assumed that the trees to be removed would be those most likely to be killed by gypsy moth defoliation (Gottschalk 1993, Gottschalk and MacFarlane 1992). Gypsy moth tends to kill higher proportions of the low-vigor trees. Although tree vigor ratings have not been done in these particular stands, established estimates of tree vigor were used from similar stands in Pennsylvania where the rate of tree mortality was measured as the gypsy moth established itself over the past two decades (Gottschalk et al. In press). These stands were comparable in species composition, stand density, and site conditions, and it is expected that similar patterns of defoliation and losses will occur in the coming decade in the

Table 4.—Losses due to gypsy moth defoliation following presalvage thinning to the 80-percent line for 24 stands that will be at least 90 percent of fully stocked in 1997.

Stand category	— Trees lost — All	0-6	6+	Stocking reduction	Basal area lost	Volume lost
	Trees/acre			Percentage	ft²/acre	MBF/acre
				Heavy Outbreak		
Average	[60.1]	[94.2]	34.1	38.0	43.5	1.5
Best	[106.1]	[137.0]	19.0	30.0	34.9	2.9
Worst	[26.0]	[57.0]	62.0	53.0	56.4	3.6
	Light Outbreak					
Average	[1.6]	[2.6]	1.0	2.8	3.4	0.3
Best	[10.0]	[13.0]	[1.0]	1.0	2.0	0.1
Worst	1.0	1.0	3.0	5.0	5.7	0.5

Note: the brackets indicate a net gain rather than a loss.

Dorr Run area. Vigor is rated using a three class system (Gottschalk and MacFarlane 1992) that provides significant differences in mortality prediction power by species groupings, canopy position, and defoliation intensity (Gottschalk et al. In press, Colbert et al. In press). Tree vigor rating was the single strongest predictive variable, followed by canopy position of a tree, while species group and defoliation showed nearly equal but slightly less significant predictive power.

We next considered minimal intervention, removing only the most vulnerable trees from the most heavily stocked stands. To make that assessment, we started with the same 1997 conditions and interposed the removal of those trees that are most likely to be killed by future gypsy moth outbreaks (trees with dieback or poor vigor). Of the 38 sample stands, 24 were sufficiently overstocked (relative density greater than 90 percent of fully stocked, Stout and Nyland 1986) to be considered for minimal removals to the 80-percent line. Following the removal of those trees, we again grew the stands forward 10 years to look for changes in the descriptive measures provided above. Three projections were run over the same 10-year period following simulated presalvage entries in 1997 (Table 4).

The stem count, basal area, and volume data used to generate Table 4 were also used to generate the "80%" box-and-whisker plots in Figures 4-6. The most obvious effect is that removals done as presalvage thinning will not only save residual stocking, but also will increase the number of trees significantly. Many of the new trees will be of the same species as the trees removed because the root systems of live cut trees will allow for stump sprouting to occur. Note that this minimal presalvage harvest also saves, on average, 18.7 ft²/acre (62.2-43.5) of basal area and increases relative stocking by 17.4 percent. These translate into a relative increase of 30 percent over the no action alternative. That is, there can be an expected saving of 30 percent of the residual basal area that would otherwise be lost due to severe gypsy moth defoliation. It should be noted that these differences do not consider those trees removed during the thinning operations.

The second option considered was a heavier presalvage cut to remove more low-vigor trees, recover more of the projected loss, and have a healthier (faster growing) residual stand. In these scenarios, we considered presalvage thinning to a level that would maximize available growing space while maintaining recommended stocking levels (the B-line or 60 percent relative stocking). Of the 38 stands used in the analysis, 31 qualified for such management in 1997. Following this simulated removal in 1997, we projected stand growth through the 1998-2007 decade and again compared the differences between the moderate and heavy outbreak scenarios and the no-outbreak scenario (Table 5).

This level of presalvage thinning further reduces the overall impact of gypsy moth. It should be noted that the assumption here has not been to reduce the severity of defoliation, but rather to reduce the expected level of tree mortality by removing trees expected to die as a result of a gypsy moth outbreak. Preventative treatments offer substantial economic savings and improve the overall health of the residual forest. Enhanced by increased growing space and nutrient availability, both regeneration and residual trees respond with improved growth and vigor. Furthermore, these conditions improve the tree's chances to recover from defoliation with minimal damage, as is demonstrated in the heavy outbreak scenarios when we compare the average stocking among these three tables. Loss in stocking drops from a 45 percent loss with no management, to 38 percent when lightly thinned, and to a 27.6 percent loss when these forest

Table 5.—Losses due to gypsy moth defoliation following presalvage thinning to the 60-percent line for the 31 stands that will be at least 70 percent fully stocked in 1997.

Stand category	Trees lost	Stocking reduction	Basal area lost	Volume lost
	Trees/acre	Percentage	ft²/acre	MBF/acre
		Heavy Outbreak		
Average	[29.5]	27.6	32.4	2.1
Best	[80.0]	15.0	22.0	1.5
Worst	14.0	39.0	41.3	2.7
		Light Outbreak		
Average	2.7	1.5	1.9	0.1
Best	[4.0]	1.0	1.1	0.0
Worst	7.0	3.0	3.8	0.3

Note: the brackets indicate a net gain rather than a loss.

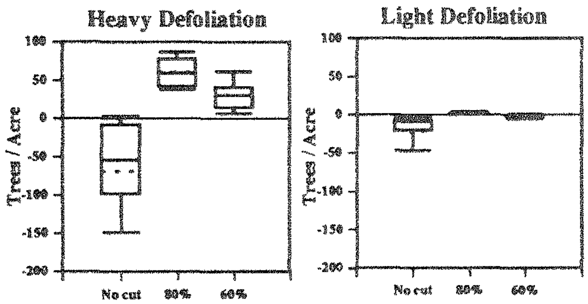

Figure 4.—Tukey box plots of predicted tree count differences in 2007 under the three alternative silvicultural practices. The whiskers are at 5 and 95 percent of the data range while the boxes span the 25 to 75 percent range with a solid 50th percentile and a dashed mean line.

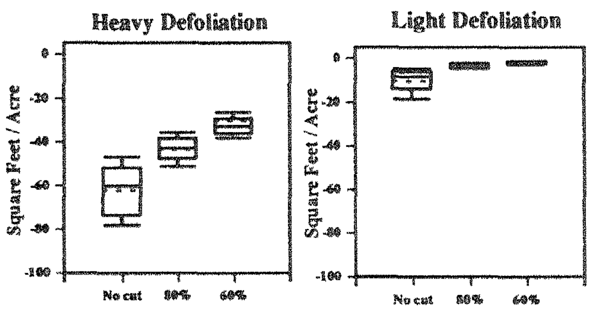

Figure 5.—Tukey box plots of basal area differences in 2007 under the three alternative silvicultural practices.

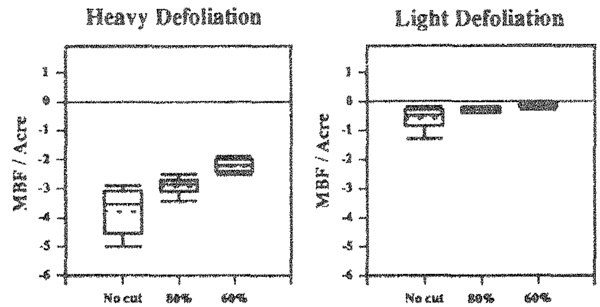

Figure 6.—Tukey box plots of standing volume differences in 2007 under the three alternative silvicultural practices.

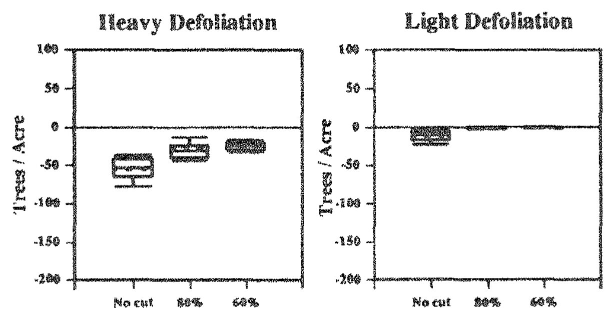

Figure 7.—Tukey box plots of predicted large (> 6 in.) tree count differences in 2007 under the three alternative silvicultural practices.

management practices are used to remove the most vulnerable trees. The end result could almost double the amount of healthy forest canopy in the average stand. To permit direct comparisons with Tables 3 and 4, we again summarize just the 24 heaviest stocked stands after cutting to the B line (Table 6).

Table 6—Losses due to gypsy moth defoliation following presalvage thinning to the 60-percent line for the 24 stands that will be at least 90 percent fully stocked in 1997.

Stand category	— Trees lost — All	0-6	6+	Stocking reduction	Basal area lost	Volume lost
	Trees/acre			Percentage	ft²/acre	MBF/acre
				Heavy Outbreak		
Average	[30.2]	[55.5]	25.3	28.8	33.0	2.2
Best	[80.0]	[103.0]	15.0	22.0	26.6	1.9
Worst	[3.0]	[21.0]	45.0	39.0	41.3	2.7
				Light Outbreak		
Average	2.8	2.2	0.6	1.7	2.1	0.2
Best	[1.0]	[1.0]	[1.0]	1.0	1.1	0.1
Worst	7.0	6.0	2.0	3.0	3.8	0.3

Note: the brackets indicate a net gain rather than a loss.

Note that basal area and volume losses increase only slightly over the values in Table 5. Contrasting these averages with those of Tables 3 and 4 show that increased intensity of presalvage thinning will increase the savings in the residual stands. Basal area losses are reduced by 30 percent under light thinning and by 47 percent under this B-line thinning. Throughout these analyses we have concentrated on the standing timber and the residual stands, not considering the revenue generated nor any other value estimates for timber removed during these presalvage thinnings. The data used to generate Table 6 also were used to generate the Tukey box-and-whisker plots labeled "60%" in Figures 4-6.

We examined these results using analysis of variance techniques to explore variation among the compartments and forest types under consideration and found no significant differences among compartments. Thus, we conclude that these results can be applied across the area and that they represent the range of expected future impacts that gypsy moth will cause as it becomes established in the Dorr Run Area.

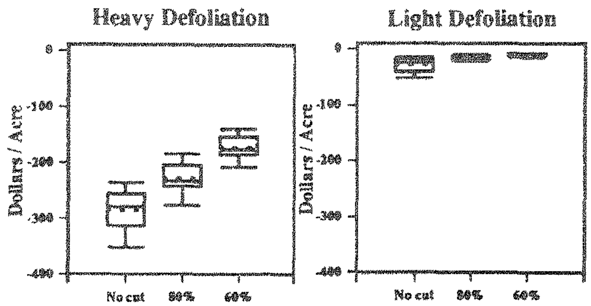

Figure 8.—Tukey box plots of volume dollar differences in 2007 (discounted to 1997 using a 5 percent rate) under the three alternative silvicultural practices.

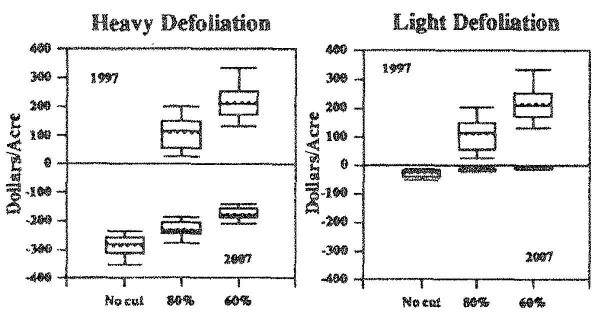

Figure 9.—Tukey box plots of present (1997) value of volume dollar differences in 2007 under the three alternative silvicultural practices, with the dollar value of the trees removed in 1997.

Ingrowth during the decade following silvicultural entry is confounding the ability to see drops in stem counts (Fig. 4). Using only trees greater than 6 inches the effect of defoliation on larger trees is apparent (Fig. 7). By comparing Figures 4 and 7, three things are made more evident: predicted ingrowth will be substantial, even in the "No cut" stands due to losses in the overstory; the range of variation in overstory stem count losses is much less than the variability in regeneration response; and silvicultural intervention will produce substantial advanced regeneration in front of the expected outbreak. Coupling these potential regeneration changes with expected basal area and volume changes in the overstory and the expected variation in average defoliation among stands following an outbreak, one can expect the losses to be reduced significantly through silvicultural intervention as selection of the highest vigor and least susceptible trees is made in the residual stands.

Dollar values of standing timber in 2007 can be viewed in current 1997 dollars by applying a 5 percent discount rate to arrive at a net present value. This provides a consistent measure for comparing current management alternatives and future stand conditions. Figure 8 shows the changes in the range of dollar values under the three management alternatives. Note that significant reductions in dollar losses are achieved under the minimal removal alternative, and further significant reductions are attained by normal B-line presalvage thinning under heavy defoliation only. These reductions are to the residual standing crop, and do not take into account the value of the 1997 removals (Fig. 9). Combining the dollar gains from sales with the losses, one sees the net value of management in Figure 10. Note that minimal presalvage thinning will nearly cut the losses from heavy defoliation in half, and B-line thinning will reduce losses by more than 75 percent.

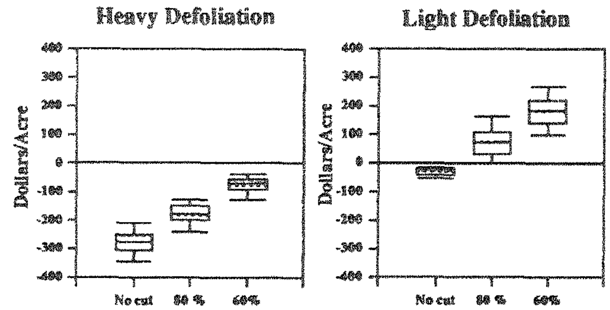

Figure 10.—Tukey box plots of net effects—sum of net present value (1997) of stands in 2007 and removal in 1997 on a stand-by-stand basis under the three alternative silvicultural practices.

CONCLUSIONS

The purpose of this study was to provide the most current management tools for silviculturists on the Wayne National Forest as they attempt to deal with the impending outbreaks of gypsy moth in southeastern Ohio. The cooperative effort provided the Wayne National Forest with the latest modelling tools and methodology integrated within a decision support shell, GypsES, that further provided the GIS tools and database resource facilities. Stand-Damage Model simulations indicate that substantial savings can be made through silvicultural management applications and that the gypsy moth can be expected to cause greater losses in the absence of management. This work provided a demonstration of management application capabilities of the models and follow-up tests done cooperatively over the coming decade will provide further examination of these working hypotheses. The stumpage prices used in this analysis are less than those in 1997 in West Virginia and Pennsylvania for these species under similar site indices. Thus, the predicted dollar losses per acre are conservative estimates, given the potential mortality. Recent presalvage and salvage treatments on the George Washington and Monongahela National Forests have shown success in providing healthy residual stands of ample productivity and were found to be profitable to local purchasers.

LITERATURE CITED

Carmean, Willard H.; Hahn, Jerold T.; Jacobs, Rodney D. 1989. **Site index curves for forest trees species in the eastern United States.** Gen. Tech. Rep. NC-128. St. Paul MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 142 p.

Colbert, J. J.; Perry, Phil; Onken, Brad. In press. **Predicting potential damage from gypsy moth defoliation and designing management actions to ameliorate losses.** Fosbroke, Sandra L. C., Gottschalk, Kurt W., eds. Proceedings, U.S. Department of Agriculture interagency gypsy moth research forum 1997; 1997 January 14-17; Annapolis, MD. Gen. Tech. Rep. NE-xxx. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Colbert, J. J.; Racin, George. 1995. **User's guide to the Stand-Damage Model: a component of the Gypsy Moth Life System Model (Version 1.1) [Computer program].** Gen. Tech. Rep. NE-207. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 38 p. [1 computer disk (3-1/2 in.); User's manual.]

Colbert, J. J.; Sheehan, Katharine A. 1995. **Description of the Stand-Damage Model: a component of the Gypsy Moth Life System Model.** Gen. Tech. Rep. NE-208. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 111 p.

Gottschalk, Kurt 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, Kurt W.; Colbert, J. J.; Feicht, David L. In press. **Tree mortality risk of oak due to gypsy moth.** European Journal of Forest Pathology. 12 p.

Gottschalk, Kurt W.; MacFarlane, W. Russ. 1992. **Photographic guide to crown condition in oaks: use for gypsy moth silviculture.** Gen. Tech. Rep. NE-168. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Gottschalk, Kurt W.; Thomas, Susan J.; Twardus, Daniel B.; Ghent, John H.; Colbert, J. J.; Teske, Milton H. 1996. **GypsES: A decision support system for gypsy moth management.** In: Shore, Terry L. ; MacLean, David A., eds. Decision Support Systems for Forest Pest Management. Proceedings of a workshop at the Joint Meeting of the Entomological Societies of Canada and British Columbia; 1995, October 17; Victoria, BC. FRDA Report No. 260. Canada-British Columbia partnership Agreement on Forest Resource Development: FRDA II. November 1996. Pacific Forestry Centre, 506 W. Burnside Rd., Victoria, BC V8Z 1M5. Canadian Forest Service: 1-8.

Liebhold, Andrew M.; Gottschalk, Kurt W.; Luzader, Eugene R.; Mason, Douglas A.; Bush, Renate; Twardus, Daniel B. 1997. **Gypsy moth in the United States: an atlas.** Gen. Tech. Rep. NE-233. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 36 p.

Liebhold, Andrew M.; Gottschalk, Kurt W.; Muzika, Rose-Marie; Montgomery, Michael E.; Young, Regis; O'Day, Kathleen; Kelly, Brooks. 1995. **Suitability of North American tree species to gypsy moth: a summary of field and laboratory tests.** Gen. Tech. Rep. NE-211. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 34 p.

Northeastern Area State and Private Forestry. 1995. **Gypsy moth management in the United States: a cooperative approach**: Final environmental impact statement, November 1995. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. Vol. I-V.

Stout, S. L.; R. D. Nyland. 1986. **Role of species composition in relative density measurement in Allegheny hardwoods.** Canadian Journal of Forest Research. 16: 574-579.

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Communicating Old-Growth Forest Management on the Allegheny National Forest

Brad Nelson[1], Chris Nowak[2], Scott Reitz[1], Dave deCalesta[2], and Steve Wingate[1]

Abstract.—Successful communication of old-growth management, including the role of silviculture, is achieved by integrating as a working whole the topics addressed in this workshop. We have used research, technology transfer and adaptive management to achieve this integration on the Allegheny National Forest. Program success depends on scientists and practitioners working together. Scientists spend more time in joint technology transfer activities and helping practitioners implement operational-level trials of new silviculture, including co-development of inventory and monitoring plans. Practitioners too have increased technology transfer responsibilities. Practitioners must think more like researchers, conceiving and applying innovative management but also developing ways to monitor the effects of those treatments.

INTRODUCTION

Successful communication of the role of silviculture in old-growth forest management is achieved by integrating, as a working whole, the topics outlined in this meeting's agenda: policy, inventory and monitoring, research, demonstration, education, and partnerships. To achieve this integration in managing old-growth forests on the Allegheny National Forest (ANF) we have:

(1) listened to the public to understand their values and needs,
(2) implemented new research to answer questions,
(3) used adaptive management to learn as we go,
(4) led discussions and field trips to reach agreement on policies,
(5) spread the word to increase knowledge and understanding of old-growth forests, and
(6) welcomed partners to join us in developing a better understanding of old-growth.

Conservation of biological diversity has become an important focus of forest management (Society of American Foresters 1991). Providing all forest seres across the landscape from early-successional through old-growth is one approach to achieving this goal (Harris 1984; Hunter 1989; Oliver and Larson 1996). In Pennsylvania, recent efforts to promote the conservation of biodiversity have called for the protection and enhancement of old-growth forests (McGuinness 1995; Rooney 1995).

Most eastern forests are dominated by early to mid-successional communities. Only about one-half of one percent of Pennsylvania's forests are old-growth (Smith 1989). Interest in preserving existing old-growth, finding new remnants, and developing old-growth from younger forests is growing in the Northeast.

The challenges of communicating old-growth forest management are many:

-LISTENING - Practitioners and researchers must understand the values (ecological, social, visual, and spiritual) the public associates with eastern old-growth.

-UNANSWERED QUESTIONS - Researchers must investigate the ecology of old-growth including studies of structure, functions and processes associated with old-growth forests and convey this information to practitioners and the public.

-LEARNING AS WE GO - Researchers and practitioners should employ adaptive management strategies to restore old-growth characteristics and monitor succession.

-GETTING EVERYONE ON THE SAME PAGE - Researchers, managers, policy makers, and the public must develop a common understanding and reach agreement on old-growth policy.

-SPREADING THE WORD - Education is a continuous process. As researchers and practitioners learn more about eastern old-growth, we should take every opportunity to convey this to the public.

-JOINING IN THE FUN - As interest in eastern old-growth grows, opportunities to develop partnerships for research, technology transfer, and adaptive management will increase.

This paper describes how communication between practitioners, research scientists, and the public have aided the development and understanding of old-growth management on the Allegheny National Forest.

LISTENING

In 1986 when we began implementing the Forest Plan we designated old-growth on a project-by-project basis. For example, if we were proposing a timber sale in an area, we would designate about five percent of the area as old-growth as specified in the Forest Plan. The public questioned our approach, stating that it was rather piecemeal and didn't clearly demonstrate what old-growth values we were trying to promote.

In response to these comments, an interdisciplinary team was formed to evaluate old-growth values on a landscape scale. The result was a landscape approach to providing old-growth values that connected the large forested parcels with continuous canopy corridors. These large, relatively unfragmented parcels include the 10,000 acre Hickory Creek

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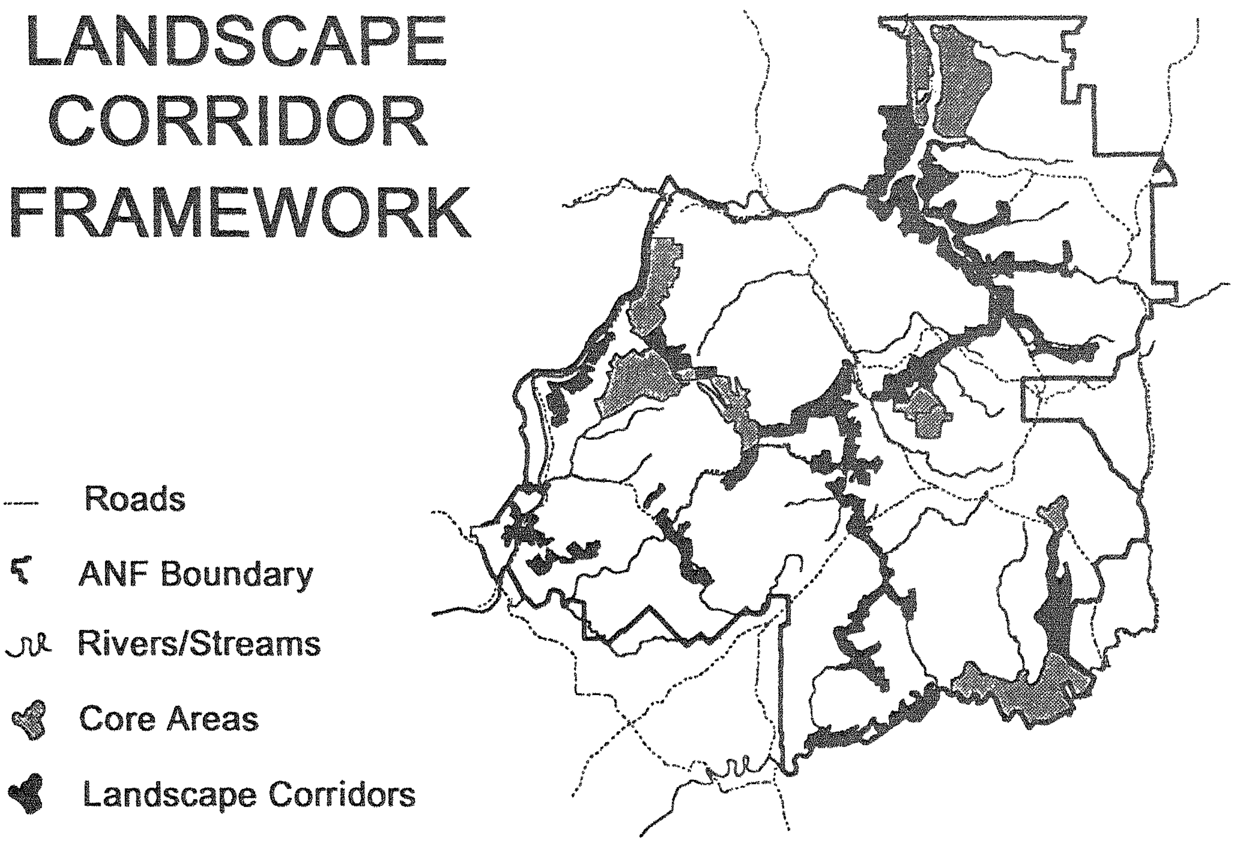

Figure 1.—Landscape corridor and core areas designated for late-successional and old-growth forests and related values on the Allegheny National Forest.

Wilderness, 9,000 acre Tracey Ridge National Recreation Area, 3,000 acre Cornplanter National Recreation Area, 7,400 acre Allegheny Front National Recreation Area, 4,100 acre Tionesta Scenic and Research Natural Areas, 3,400 acre Clarion River area, 1,300 acre Minister Valley area, and 1,400 acre Brush Hollow area. These core areas are connected by 82,000 acres of corridors (Fig. 1).

Four primary objectives for the corridor were identified by the team: connectivity, late successional/old growth habitat, riparian values, and social and amenity values (Allegheny National Forest 1995). The connectivity objective is intended to facilitate the movement of less mobile species such as amphibians, reptiles, and small mammals so they can leave areas of disturbance that do not fully meet their habitat needs and repopulate nearby areas that are recovering from past disturbance; enhance habitat for forest interior neotropical migratory songbirds by providing large blocks of contiguous forest; and facilitate genetic flow between metapopulations of less mobile species, including trees. The late successional/old-growth forest habitat objective is intended to provide habitat to meet the needs of threatened, endangered, and sensitive species; provide habitat for species requiring isolation from major human activities, species that use cavities, and species that use large woody debris; and promote ecological processes (energy flows, nutrient cycles, hydrologic cycles) that develop in late successional forests. The riparian objective is intended to complement on-going ANF initiatives to improve fisheries habitat by developing a stable source of large woody debris for some streams; and complement the on-going ANF initiatives to maintain or improve water quality and reduce sedimentation through protection of riparian areas. The social and amenity objective is intended to maintain and enhance visual quality of the forest, especially in sensitive viewsheds; and maintain and enhance recreational and amenity values associated with late-successional and old-growth forests.

A brochure and table-top display were developed to solicit additional public comments on the landscape corridor approach. Presentations and/or displays were given at more than 18 conferences, workshops, and meetings and 36 individuals responded in writing. With this input we designed the landscape corridor to meet a variety of objectives, functions, and values. While old-growth values are featured in the corridor, other objectives may be more important in some areas than in others (Allegheny National Forest 1995).

UNANSWERED QUESTIONS (RESEARCH)

Over the course of the last decade, we have learned of many unanswered questions for old-growth management on the ANF. We have also learned that much research has been conducted in ecology and silviculture, all the way back to the 1920s, that is useful in old-growth management today. Research answers and needs can be organized into three areas: ecosystem dynamics, human dimensions, and silviculture and resource management. We present a brief history and the questions yet to be answered in each.

Ecosystem Dynamics

We need research in ecosystem dynamics to gain insights into ecological states and processes of old-growth. Our goal is to learn about ecological capabilities so that desired future conditions for stands and landscapes can be developed, and management programs can be implemented that may include silviculture to sustainably promote old-growth values.

Ecological research extends back to the late 1920s with the work of Hough, Lutz, Morey and others. At that time, there were still tens of thousands of acres of virgin forest within the 700,000 acre ANF proclamation boundary. Scientists studied many of these forest as they were being cut. In one such study, Hough and a crew of over 20 from the Civilian Conservation Corps aged 100s of trees across a 7,000 acre hemlock-hardwood old-growth remnant as it was being cut (Hough and Forbes 1943).

Today, less than 5,000 acres of remnant old-growth exists on the ANF, most of that in the 4,100 acre Tionesta Scenic and Research Natural Area. This remnant and others, including Hearts Content, a 120 acre white pine-hemlock-hardwood remnant, have been valuable for studying old-growth. Over 50 research papers have been written on the Tionesta and Hearts Content areas, with 15 on-going studies across both areas today. A key to our old-growth management program has been the availability of the Tionesta and other remnants, both for education and for research.

Studies in the past focused on the state of old-growth with detailed descriptions of tree size and age distributions and species composition. There were few function- or process-level studies, with the exceptions being Hough's studies of regeneration, succession, and soil-site-species relations. Landscape perspectives on old-growth were anecdotal.

We need more basic information on ANF old-growth, including more information on states (e.g., coarse woody debris, wildlife communities, fungi, and invertebrates). Future research should be focused on understanding functions and processes. We need studies in disturbance regimes, forest stand dynamics, soil development, biogeochemical cycling, and species-site relations. While we have current studies in many of these areas, we need many more, and we need them soon.

Human Dimensions

Research defines the values people derive from old-growth and determines whether management can culture stand and landscape conditions to provide those values. We have learned some of this through the National Environmental Policy Act process and our experiences in information and technology transfer, but much could be learned with formal social study.

Silviculture and Resource Management

Silviculture is becoming recognized as having a prominent role in restoring and sustainably maintaining old-growth ecosystems. For the ANF, indepth silviculture knowledge is available. Many of the same scientists who described the old-growth forest during the 1920's and 1930's, as cited above, also conducted silviculture research. Preliminary silviculture guides were developed by Hough and others in the 1940's and 1950's (Hough 1953, 1959; Hough and Forbes 1943). These guides have been substantially revised and expanded (Marquis et al. 1992; Marquis 1994). While silvicultural techniques and methods were chiefly developed for timber values, they can be modified to achieve old-growth values. New silvicultural practices can be developed specifically for old-growth. We are presently using both old and new silviculture to restore some old-growth values to the ANF.

LEARNING AS WE GO (ADAPTIVE MANAGEMENT)

We have implemented some of our knowledge of ecosystem dynamics, human dimensions, and silviculture into operational-level forest management using an adaptive management approach. We have released subordinate conifers in maturing hardwood forests. We have underplanted conifers in partial cut hardwood stands. And we have maintained coarse woody debris during tornado salvage and enhanced coarse woody debris during partial cutting. We have demonstrated these practices, and related them to desired future conditions to generate reaction and feedback from stakeholders. We are in the process of analyzing the results of these interactions and will, if necessary, refine or change management practices so as to better achieve the desired future conditions.

All of these treatments—conifer planting and release and proactive management of coarse woody debris by leaving or creating large dead wood structures—took place in the landscape corridor (see previous section). The corridor and its core areas are the key to ANF old-growth. The core areas include both old-growth (Tionesta and Heart's Content) and unmanaged second-growth forest which will develop into old-growth in 200+ years. There are nearly 40,000 acres of core areas. The 82,000 acres of landscape corridor will be managed proactively to meet objectives, including old-growth values. We will continue to work on developing desired future conditions for this area, alter the vegetation with silviculture to accelerate attainment of these conditions, and monitor the effects of silviculture treatments in sustainably providing old-growth values. We are exploring management buffer zones around the core areas. And in addition to the landscape corridor-core area system, small remnants of old-growth outside the corridor-core areas will continue to be preserved. In total, nearly 25-percent of the ANF is being managed for old-growth values.

Major disturbances may occur in the landscape corridor that could jeopardize some of the late-successional and old-growth values that we are striving to perpetuate. Insect and disease outbreaks of native and exotic species and cyclic windstorms, particularly tornadoes, will result in the loss of some portion of overstory trees, increasing the amount of light reaching the forest floor and increasing the amount of dead wood in the forest. If a catastrophe results in substantial tree mortality such that connectivity and late successional objectives cannot be met, restoration activities that feature silviculture such as planting and fencing to prevent overbrowsing by deer may be implemented.

GETTING EVERYONE ON THE SAME PAGE (CONSISTENT POLICY - TECHNOLOGY TRANSFER)

Multiple objectives, refined definitions, and taking a long term view at a broader scale are factors that have contributed to the complexity of the landscape corridor/old-growth concept. On the Allegheny National Forest, we have found that discussing old-growth issues in the woods gives all participants a common understanding of the complex situation and helps us reach agreement and consensus. We have spent a day with the ANF Forest Leadership Team in Tionesta Scenic and Research Natural Areas viewing and discussing the differences between late-successional forests and true old-growth, and how species composition, levels of dead wood, and wildlife use change as forests become older. We have reviewed the implementation of some of our corridor projects with many ANF employees and publics to determine if we did what we said we would do and if we achieved the results we were striving for.

SPREADING THE WORD (EDUCATION)

Perhaps it is obvious, but we should take every opportunity to share information and explain to the public our late-successional and old-growth policy. Although not always possible, we believe the best way to communicate our message is in the woods viewing old-growth first hand. Last year we led field discussions with more than a dozen groups (>200 people) to discuss old-growth on the ANF.

Discussions of succession and how old-growth characteristics develop over time have helped people understand how old growth develops. A simple distinction between late-successional forests and old-growth forests has helped us communicate the importance of time in developing old-growth values. Late-successional forests, transitional old-growth, and potential old-growth are all used to describe forests between 111 and 300 years old (111 years is used in the ANF's Forest Plan as an old-growth theshold). Forests older than 300 years are defined as true old-growth or ecological old-growth. These definitions, which follow the recommendations of Oliver and Larson (1996) and research results specific to hemlock-hardwoods by Tyrrell and Crow (1994), have been useful in discussing the temporal aspects of old-growth values and how some old-growth values accrue during the late-successional forest stage and peak during the old-growth stage. Discussion of the spatial aspects of old-growth, embodied in the landscape corridor itself, have benefitted from Mladenoff et al.'s (1993) and Lorimer and Frelich's (1994) descriptions of presettlement hemlock-hardwood landscapes in the Midwest.

JOINING IN THE FUN (PARTNERSHIPS)

Interest in eastern old-growth is growing and with that interest comes many questions that warrant investigation. Many researchers have studied a piece of the puzzle, but few opportunities to bring all the pieces together have occurred. Last summer, we brought all the researchers together who have studied various components of the Tionesta Research Natural Area. Each researcher had the opportunity to discuss his/her research and learn from the research findings of others. The result was a better and more holistic understanding of eastern old-growth and the generation of more questions that need investigation. We plan to continue these research cooperator meetings every other year.

To evaluate the success of the landscape corridor and core area concept in meeting identified objectives, a carefully designed monitoring program should be implemented. This program can include the monitoring of selected wildlife communities, plant communities, and featured habitats such as late-successional habitats and riparian areas. We recognize that no single agency could undertake all the monitoring that is needed to answer the many questions concerning landscape corridors and late-successional forests. We openly invite colleges, universities, and other partners to become actively involved in monitoring, research, and adaptive management in old-growth forest management on the ANF. To meet this end, we have taken our show on the road, soliciting scientific input from outside the Forest Service through various workshops and field tours. A workshop we ran this past spring at The Pennsylvania State University resulted in two new research projects, one on hemlock wooly adelgid and the other on watershed nitrogen dynamics, both to occur in the old-growth on the Tionesta Scenic and Research Natural Area.

IN CLOSING ...

The success of communicating old-growth policy and the role of silviculture in management of old-growth forests depends on scientists, practitioners, and the public working together. Scientists spend more time in joint technology transfer activities and helping forest managers implement operational-level trials of new forest management. Practitioners must understand the values that the public associates with old-growth forests and incorporate these values into old-growth management policies. Practitioners must continue to conceive and apply innovative management, and also develop research-like ways to monitor the effects of those treatments. Each—scientist and practitioner—needs to spend more time helping others understand their own knowledge and experience. Synergism will occur. Policy and practice will change and our understanding of old-growth will increase, all to the benefit of the forest.

LITERATURE CITED

Allegheny National Forest. 1995. **Appendix D. A landscape approach to providing late-successional forests and associated functions and values on the Allegheny National Forest.** In: Analysis of timber harvest program capability, 1995 through 2005. Allegheny National Forest, Warren, PA.

Harris, L. D. 1984. **The fragmented forest.** The University of Chicago Press, Chicago.

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

Hough, A. F. 1959. **Zoning for the management of black cherry on the Allegheny Plateau.** Journal of Forestry 57: 353-357.

Hough, A. F.; Forbes, R. D. 1943. **The ecology and silvics of forests in the high plateaus of Pennsylvania.** Ecological Monographs 13: 299-320.

Hunter, M. L., Jr. 1989. **What constitutes an old-growth stand? Towards a conceptual definition of old-growth forests.** Journal of Forestry 87(8):33-35.

Lorimer, C. G.; Frelich, L. E. 1994. **Natural disturbance regimes in old-growth northern hardwoods: implications for restoration efforts.** Journal of Forestry 92: 33-38.

Mladenoff, D. J.; White, M. A.; Pastor, J.; Crow, T. R. 1993. **Comparing spatial pattern in unaltered old-growth and disturbed forest landscapes.** Ecological Applications 3: 294-306.

Marquis, D. A., ed. 1994. **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. 376 p.

Marquis, D. A.; Ernst, R. L.; Stout, S. L. 1992. **Prescribing silvicultural treatments in hardwood stands of the Alleghenies (revised).** Gen. Tech. Rep. NE-96. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 101 p.

McGuinness, B. J. (ed.). 1995. **A heritage for the 21st century:** Conserving Pennsylvania's native biological diversity. Pennsylvania Fish and Boat Commission, Harrisburg, PA.

Oliver, C.D.; Larson, B. C. 1996. **Forest stand dynamics.** Update edition. John Wiley and Sons, Inc., New York.

Rooney, T. P. 1995. **Restoring landscape diversity and old growth to Pennsylvania's northern hardwood forest.** Natural Areas Journal 15:274-278.

Smith, T. L. 1989. **An overview of old-growth forests in Pennsylvania.** Natural Areas Journal 9:40-44.

Society of American Foresters. 1991. **Task force report on biological diversity in forest ecosystems.** Society of American Foresters SAF 91-03, Bethesda, MD.

Tyrrell, L. E.; Crow, T. E. 1994. **Structural characteristics of old-growth hemlock-hardwood forests in relation to age.** Ecology 75: 370-386.

Use of Expert Systems for Integrated Silvicultural Planning

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Abstract.—The use of silvicultural treatments in hardwood stands presents opportunities for increasing the growth and yield of quality sawtimber and enhancing the suitability of the site for use by numerous species of wildlife. Planners, loggers, and managers must consider multiple aspects of the ecosystem when making silvicultural decisions. In this paper we demonstrate an integrated expert system called FOREX and explain how it can be used to make silvicultural decisions that integrate potential growth and yield, logging technology, economics, wildlife, markets, log prices, and the time value of money.

INTRODUCTION

Owners of forested land are being challenged to meet ecosystem/landscape level goals while meeting personal and financial objectives. This challenge is further complicated by the need for integrated planning, i.e., considering all of the present and potential values and benefits available from forested ecosystems. Information on wildlife habitat, silvicultural practices, logging technology, economic and market factors, and the time value of money must be integrated when deciding how to manage forest lands. The natural process of forest establishment, growth, and development must be studied to better understand the potential values and benefits of proposed silvicultural treatments over time.

Forest ecosystems undergo a series of seral stages that lead to a climax state over time (Odum 1969; Hunter 1990). For example, many ecosystems left undisturbed undergo a series of stages because system changes are constant over time. The vegetation at each stage in the process suits different creatures and different people at different times. As the forest moves through these seral stages, wildlife comes and goes. for example, a thicket-like stand at age 30 will have few grouse and gray fox by age 60. Or a forest stand may be in the pole-timber class for 30 to 50 years as part of its 90- to 200-year rotation age. In this stage, trees of the same species kill each other in competition for light, nutrients, and water (Odum 1969). Also during this phase, many different species of wildlife occupy and use the site (DeGraaf et al. 1991) and also kill each other in a natural struggle for survival (Dasmann 1964; Odum 1969; Hobson et al. 1993; Black 1994). During this period, 30 to 50 years, many plant, tree, and wildlife species can be harvested without stopping or setting back the process.

At some point in this natural process, forests contain fewer but larger trees. These "larger" woods seem to be those that many people want to protect and/or keep constant. But nature does not stand still. In fact, goals for timber production often mimic the natural process of succession. For example, researchers have demonstrated that thinning stands can produce trees that are more valuable and faster growing than those in many unmanaged stands. It is to everyone's advantage to understand and plan for the potential products, values, and benefits that forest stands yield over time. It also is important that managers understand the economic implications of their actions and are able to evaluate the economic tradeoffs that result from alternative silvicultural treatments.

Another major concern of owners is bringing together the volumes of research information on wildlife habitat, stand management, logging technology, economic and market factors, and the impact of time when deciding how to manage their forest land. This challenge is complicated in that the vegetation and various organisms that make up a forest ecosystem survive and reproduce on a site because they have adapted to their physical environment and are able to coexist with one another. When humans disturb this balance by removing vegetation from the site or changing its species composition, the site may no longer be suitable as habitat for certain wildlife species. Managers can avoid much of this potential disruption to wildlife by maintaining the natural/original species composition of the site/stand. This may best be achieved by the use of natural regeneration following disturbance/regeneration versus regenerating the site with artificial methods that favor one species of vegetation over another (Hunter 1990).

A second complication is the lack of decisionmaking software/tools that allow for integration across disciplines. As a result, land owners usually manage their land according to personal experience. Often, the result is the continued implementation of a handful of silviculture practices that may not meet all of the owner's objectives.

We have developed an expert system called FOREX that allows integrated decisionmaking in managing of hardwood forests (LeDoux et al. 1995; 1996; LeDoux 1997). FOREX considers the potential growth and yield, products, and development of a stand over time, economic and market factors, and impacts on wildlife habitat. This system can be applied to all forest types in the Northeast, and currently considers impacts on wildlife habitat for New England forest types. Wildlife data from other forest types and regions will be incorporated into the FOREX database as they become available. In this paper we explain how FOREX can be used to evaluate the flow of potential products, values, and benefits associated with a forested stand over its life.

Description of FOREX

FOREX uses data from simulation runs from a model called MANAGE (LeDoux 1986; LeDoux et al. 1995). The user can obtain information on present net worth (PNW), optimal

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timing of thinning entry, optimal economic stand-rotation age, average diameter at breast height (dbh), volume by grade and value of the trees harvested, and, depending on the cable yarder or ground-based system used, average slope yarding or skid distance, truck class, road class, log-bucking methods, and number of thinnings desired. FOREX also provides information on the effect of harvesting treatments on wildlife habitat. Users can obtain data on the PNW, dbh, and volume required for a specific set of management objectives, and perform a sensitivity analysis that eliminates the need to sort through numerous simulations.

FOREX also can be used to project growth and volume yields, yields of individual wood products, estimate stump-to-mill logging costs, predict cash flows and discounted PNW revenues, project the suitability of habitat for wildlife, estimate optimal periods between thinnings or other silvicultural treatments. From these data, users can gauge the impact of various silvicultural treatments on wildlife and evaluate management tradeoffs such as longer rotations for wildlife versus shorter ones for fiber production.

Stand Conditions Used

For this demonstration, we used a stand from the northern red oak forest cover type. The species mix includes chestnut oak, scarlet oak, black oak, hickories, red maple, and red oak. The average site index is about 70. The stand is 30 years old and contains about 330 trees per acre that are more than 5 inches dbh; the average stand diameter is 6.37 inches dbh. The stand is on moderate to steep slopes and could be harvested by cable or ground-based systems. The site is covered with greater than 25 percent rock cover, has greater than 30 percent forest litter cover, has active seeps, loose soils and small caves, and has at least 50 ft^3/acre of dead and down material on the forest floor. The land has about 20 percent shrub cover and at least 29 percent ground cover. For this demonstration, the management block is assumed to be 300 acres in size for harvesting and wildlife purposes. We input the stand information into FOREX and conducted several consultation runs to determine the potential benefits, costs, and values associated with managing such a stand.

RESULTS

The stand was subjected to thinnings at age 60, 70, and 150, with an optimal rotation age of 160 years. An additional objective of the last thinning at age 150 was to promote advanced regeneration before final harvest. The tract was logged with both cable and ground-based systems (Table 1).

Potential Growth and Yield

The stand would yield 751.20 ft^3 of wood at age 60 with an average dbh of 9.93 inches (Table 1). Thinnings at age 90 and 150 would yield 1,752.58 and 2,132.09 ft^3 respectively, and the final harvest would yield 3,627.75 ft^3. Extending the final harvest to 200 years would yield 4,362.74 ft^3.

Potential Product Yields

At age 60, the product mix consists of a small quantity of grade 3 logs with the remainder in pulpwood (Table 1). The second and third thinnings yield more grade 1 and grade 2 volume. For example, the third thinning and final harvest have high percentages of grade 1 and grade 2 logs. The final harvest has the highest proportion of grade 1 volume because the three previous thinnings favored leaving the best crop trees for final harvest. Extending the final harvest to 200 years would yield a large proportion of grade 1 logs.

Optimal Thinning Entry and Rotation Age

FOREX can be used to estimate the optimal timing of thinning entry. For this demonstration, the optimal thinning schedule is age 60, 90, and 150 with an optimal rotation length of 160 years. The thinnings can be constrained so that they break even or generate a profit before they are considered feasible, that is, the value of the products removed must pay their way to the mills.

FOREX also projects the optimal rotation age given any prior treatment(s). In this case, the stand is thinned at age 60, and the residual stand is projected to age 90 and thinned, and the residual stand at age 90 is projected to age 150 and thinned, and the residual stand at age 150 is projected forward until it reaches the optimal rotation age of 160.

Potential Monetary Yields

FOREX also projects the cash flows and PNW for each combination of thinning entry and optimal rotation. For example, thinning at age 60 would require a subsidy of $123.98 or $105.39/acre for cable and ground-based systems, respectively. Accordingly, data on PNW and cash flow are presented for each thinning, final harvest, or extended rotations. Thinnings at age 90 and 150 are economical, yielding a PNW of $86.40 or $82.53/acre depending on the logging method used.

Management Tradeoffs

FOREX can be used to evaluate/rank alternative management tradeoffs. For example, the optimal rotation at age 160 yields a PNW of $107.65 and $118.09/acre for cable and ground-based harvests, respectively. Extending the rotation to 200 years results in a PNW value of $48.83 and $53.11/acre, for cable and ground-based systems. The tradeoff in PNW represents a reduction of about 55 percent for ground-based harvests, or a net loss of about $1.62/acre/year. Although cash flows for the extended rotation are larger than those from optimal rotations, the time value of money makes future yields worth less in PNW.

Wildlife Habitat Suitability

FOREX links actual stand attributes such as dbh, volume per acre, number of trees per acre, species mix, and other stand/site attributes with guidelines of DeGraaf et al. (1992) to generate lists of potential wildlife species that would find the

Table 1.—FOREX results by treatment for 30-year old northern red oak forest stand

Attribute	Thinning 1[a]	Thinning 2[b]	Thinning 3[b]	Final harvest	Extended rotation
Yarding distance (ft)	600	600	600	600	600
Buck type	1	1	1	1	1
Road class	3	3	3	3	3
Truck class	2	2	2	2	2
Age (years)	60	90	150	160	200
Trees (no.)	57	75	35	51	41
Avg. dbh (inches)	9.93	12.80	19.27	20.43	23.97
Volume (ft^3)	751.20	1752.58	2132.09	3627.75	4362.74
G1 (bd. ft)[c]	0	915.28	6947.64	13543.29	20652.76
G2 (bd. ft)[d]	0	601.00	161.31	402.85	127.81
G3 (bd. ft)[e]	46.67	284.46	758.93	701.66	712.17
G4 (ft^3)[f]	737.33	1320.83	650.75	987.37	813.94
PNW (dollars)[g]	-51.08	49.27	75.17	107.65	48.83
Cash flow (dollars)[g]	-123.98	290.28	2609.22	5021.73	7430.94
PNW (dollars)[h]	-43.42	86.40	82.53	118.09	53.11
Cash flow (dollars)[h]	-105.39	509.03	2864.70	5508.74	8082.38

[a]20 percent of trees/acre removed.
[b]40 percent of trees/acre removed.
[c]G1 = grade 1 volume/acre.
[d]G2 = grade 2 volume/acre.
[e]G3 = grade 3 volume/acre.
[f]G4 = pulpwood/acre.
[g]Cable systems.
[h]Ground-based systems.

site/stand suitable. For example, the 160-year-old stand would yield conditions acceptable to several species of amphibians, birds, mammals, and reptiles (Table 2). Table 3 lists the potential species that would find the site/stand suitable after harvest provided that down logs and tops are left on the site following final harvest. Table 4 shows the potential species that would find the site/stand suitable after final harvest when residual down logs and tops are removed/utilized after final harvest. Such consultation runs allow users to estimate the suitability of habitat for wildlife and gauge the impact of various silvicultural treatments on wildlife. The lists produced by FOREX were cross-validated using the HAM model (Harvey and Finley 1996).

CONSIDERATIONS FOR USERS

Integrated expert systems can be used to estimate the potential values and benefits associated with the management of eastern hardwoods over time. Managers, planners, and users can obtain detailed information on growth and yield, potential product development, logging costs, potential revenues, suitability of habitat for wildlife, impacts of silvicultural treatments on wildlife, timing of thinning entry and optimal rotation age. Generally, foresters can manage the resource for an array of products and values simultaneously, and users can evaluate economic tradeoffs that result from alternative silvicultural treatments.

Refinements in the data on wildlife, product quality, and other variables are being made, and additions to the knowledge base can be easily incorporated into the FOREX database. FOREX integrates the best information on logging cost, mill prices paid, and similar factors into a user-friendly system that can be used when planning silvicultural treatments.

It is doubtful that expert systems such as FOREX will replace the expertise available at the forest or district level as there is no substitute in the short run for a manager's knowledge of the land, hand-drawn maps, etc. Still, FOREX and other integrated expert systems can be useful in the decisionmaking process and thus contribute to improved management of the nation's forest resources.

Table 2.—Potential species for stand before final harvest

Redback salamander (*Plethodon cinereus)*	Black-capped chickadee (*Parus atricapillus)*
Northern brown snake (*Storeia d. dekayi)*	Tufted titmouse (*Parus bicolor)*
Northern redbelly snake (*Storeia o. occipitomaculata)*	White-breasted nuthatch (*Sitta carolinensis)*
Northern ringneck snake (*Diadophis punctatus edwardsi)*	Brown creeper (*Certhia americana)*
Northern black racer (*Coluber c. constrictor)*	Red-eyed vireo (*Vireo olivaceus)*
Black rat snake (*Elaphe o. obosoleta)*	Blackburnian warbler (*Dendroica fusca)*
Eastern milk snake (*Lampropeltis t. triangulum)*	Scarlet tanager (*Piranga olivacea)*
Northern copperhead (*Agkistrodon contortrix mokeson)*	Brown-headed cowbird (*Molothrus ater)*
Timber rattlesnake (*Crotalus horridus)*	Purple finch (*Carpodacus purpureus)*
Sharp-shinned hawk (*Accipiter striatus)*	Carolina chickadee (*Parus carolinensis)*
Northern goshawk (*Accipiter gentilis)*	Virginia opossum (*Didelphis virginiana)*
Red-shouldered hawk (*Buteo lineatus)*	Masked shrew (*Sorex cinereus)*
Broad-winged hawk (*Buteo platypterus)*	Little brown bat (*Myotis lucifugus)*
Red-tailed hawk (*Buteo jamaicensis)*	Silver-haired bat (*Lasionycteris noctivagans)*
Great horned owl (*Bubeo virginianus)*	Big-brown bat (*Eptesicus fuscus)*
Red-bellied woodpecker (*Melanerpes carolinus)*	Northern red bat (*Lasiurus borealis)*
Yellow-bellied sapsucker (*Sphyrapicus varius)*	Gray squirrel (*Sciurus carolinensis)*
Hairy woodpecker (*Picoides villosus)*	Southern flying squirrel (*Glaucomys volans)*
Eastern wood-pewee (*Contopus virens)*	Northern flying squirrel (*Glaucomys sabrinus)*
Eastern phoebe (*Sayornis phoebe)*	Coyote (*Canis latrans)*
Blue jay (*Cyanocitta cristata)*	Black bear (*Ursus americanus)*
American crow (*Corvus brachyrhynchos)*	Red fox (*Vulpes vulpes)*
Common raven (*Corvus corax)*	White-tailed deer (*Odocoileus virginianus)*
Ruffed grouse (*Bonasa umbellus)*	

Table 3.—Potential species for stand after final harvest (down logs and tops left on site)

Northern brown snake *(Storeia d. dekayi)*	Northern ringneck snake *(Diadophis punctatus edwardsi)*
Northern black racer *(Coluber c. constrictor)*	Black rat snake *(Elaphe o. obosoleta)*
Eastern milk snake *(Lampropeltis t. triangulum)*	Timber rattlesnake *(Crotalus horridus)*
Cooper's hawk *(Accipiter cooperii)*	Golden eagle *(Aquila chrysaetos)*
Blue jay *(Cyanocitta cristata)*	American crow *(Corvus brachyrhynchos)*
Common raven *(Corvus corax)*	Ruffed grouse *(Bonasa umbellus)*
Wild turkey *(Meleagris gallopavo)*	Purple finch *(Carpodacus purpureus)*
Masked shrew *(Sorex cinereus)*	Coyote *(Canis latrans)*
Black bear *(Ursus americanus)*	Red fox *(Vulpes vulpes)*
White-tailed deer *(Odocoileus virginianus)*	

Table 4.—Potential species for stand after final harvest (down logs and tops removed)

Northern ringneck snake *(Diadophis punctatus edwardsi)*	Timber rattlesnake *(Crotalus horridus)*
Cooper's hawk *(Accipiter cooperii)*	Golden eagle *(Aquila chrysaetos)*
Blue jay *(Cyanocitta cristata)*	American crow *(Corvus brachyrhynchos)*
Common raven *(Corvus corax)*	Ruffed grouse *(Bonasa umbellus)*
Wild turkey *(Meleagris gallopavo)*	Purple finch *(Carpodacus purpureus)*
Coyote *(Canis latrans)*	Red fox *(Vulpes vulpes)*
White-tailed deer *(Odocoileus virginianus)*	

LITERATURE CITED

Black, H. C., tech ed. 1994. **Animal damage management handbook.** Gen. Tech. Rep. PNW-GTR-332. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 236 p.

Dasmann, R. F. 1964. **Wildlife biology.** New York: John Wiley and Sons. 231 p.

DeGraaf, R. M.; Scott, V. E.; Hamre, R. H.; Ernst, L; Anderson, S. H. 1991. **Forest and rangeland birds of the United States-natural history and habitat use.** Agric. Handb. 688. Washington, DC: U.S. Department of Agriculture. 625 p.

DeGraaf, R. M.; Yamasaki, M.; Leak, W. B.; Lanier, J. W. 1992. **New England wildlife: management of forested habitats.** Gen. Tech. Rep. NE-144. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 271 p.

Harvey, H. M.; Finley, J. C. 1996. **Stand level assessment—a piece of the biodiversity puzzle.** In: Ecosystem management: translating concepts to practice: 1995 Penn State School of Forest Resources issues conference; 1995; University Park, PA. State College, PA: The Pennsylvania State University, School of Forest Resources: 43-50.

Hobson, S. S.; Barclay, J. S.; Broderick, S. H. 1993. **Enhancing wildlife habitats—a practical guide for forest landowners.** Publ. NRAES-64. Ithaca, NY: Northeast Regional Agricultural Engineering Service, Cooperative Extension. 172 p.

Hunter, J. L., Jr. 1990. **Wildlife, forests, and forestry—principles of managing forests for biological diversity.** Englewood Cliffs, NJ: Prentice-Hall. 370 p.

LeDoux, C. B. 1986. **MANAGE: a computer program to estimate costs and benefits associated with eastern hardwood management.** Gen. Tech. Rep. NE-112. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

LeDoux, C. B.; Gopalakrishnan, B.; Lankalapalli, K. 1995. **FOREX—an expert system for managing even-aged upland oak forests on steep terrain.** In: Gottschalk, K. W.; Fosbroke, S. L. C., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-7; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 474-480.

LeDoux, C. B.; Gopalakrishnan, B.; Mudiyanur, S. 1996. **Maximizing financial yields while meeting landowner objectives and ecosystem goals.** In: Planning and implementing forest operations to achieve sustainable forests. Proceedings of the joint meeting of the Council On Forest Engineering and International Union of Forest Research Organizations; 1996 July 29-August 1; Marquette, MI. St. Paul, MN: Council on Forest Engineering: 220-226.

LeDoux, C. B. 1997. **Evaluating timber harvesting impacts on wildlife habitat suitability using FOREX.** In: Pallardy, S. G.; Cecich, R. A.; Garrett, H. G.; Johnson, P. S. Proceedings, 11th central hardwood forest conference; 1997 March 23-26; Columbia, MO. Gen. Tech. Rep. NC-188. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 26-35.

Odum, E. P. 1969. **Fundamentals of ecology, 2nd ed.** Philadelphia, PA: W.B. Saunders Co. 546 p.

Assessing Native American Disturbances in Mixed Oak Forests of the Allegheny Plateau

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INTRODUCTION

Although much has been written concerning the ecology and disturbance history of hemlock - white pine - northern hardwood (Nichols 1935; Braun 1950) forests of the Allegheny Plateau (Lutz 1930a; Morey 1936; Hough and Forbes 1943; Runkle 1981; Whitney 1990; Abrams and Orwig 1996) few studies have investigated the distribution and successional dynamics of oak in this region. Most witness tree studies of the Plateau cite low numbers (<4%-20%) of oak with most occurring on droughty, south facing upper slopes (Lutz 1930b; Gordon 1940; Seischab 1990; Whitney 1990; Abrams and Ruffner 1995). Both Gordon (1940) and Kuchler (1964) mapped northward extensions of oak along river valleys into southern New York. While some oak communities may represent edaphic climaxes on poor, droughty soils (Gordon 1940; Braun 1950) we believe that these northward extensions may also reflect a presence of Native American fire and or agricultural clearing (Day 1953; Meltzer and Smith 1986; DeVivo 1991). Many researchers have reported the impact of Native American disturbances on pre-European settlement forests of eastern North America (Maxwell 1910; Day 1953; Chapman et al. 1982; Pyne 1983; Patterson and Sassaman 1988; Dorney and Dorney 1989; DeVivo 1991). Nearly all reference a patchwork anthropogenic landscape resulting from the burning of forests to reduce underbrush, girdle trees, improve wildlife browse, drive game, rejuvenate fruiting species or to clear agricultural fields.

Regional pollen sequences suggest oak was present on the southern New England landscape by 10,000-9,000 years BP (Watts 1979; Webb 1981; Davis 1983). Oak-pine forests replaced spruce-pine woodlands as early as 10,500 years BP coinciding with increased charcoal abundance and a warmer, drier climate (Miller 1973; Spear and Miller 1976; Calkin and Miller 1977; Sirkin 1977). While the role of fire in the historical development of oak is widely accepted for the mixed oak region (Lorimer 1985; Abrams 1992; Abrams and Nowacki 1992; Johnson 1992) this relationship has not been fully investigated in northern hardwood forests. Clark and Royall (1995) reported a transition from northern hardwood to white pine-oak forests during a period of Iroquois occupation and agricultural clearing. In their study of New England, Patterson and Sassaman (1988) compared sedimentary charcoal and archaeological site distributions and found fires were more common on coastal sites where Native populations were greatest and their land-use practices most intensive. In addition, they noted archaeological site distributions corresponded well with areas characterized by high oak pollen percentages (Dincauze and Mulholland 1977; Patterson and Sassaman 1988).

Recent paleoecological investigations have questioned the importance and extent of Native American fire usage in oak development (cf. Russell 1983; Clark and Royall 1996). Thus, while several regional studies suggest the correlation of fire occurrence and Native occupation with oak forest distribution more research must be completed to better understand the pre-European landscape across the northeast. In this study, we wish to gain an historical perspective for the development of oak forests on the Allegheny Plateau. Our objectives include: 1) elucidating what factors existed historically to foster oak development on the landscape, 2) identify processes whether natural and/or cultural driving oak distribution, and 3) identify successional status of current oak forests on the landscape. From this information, we hope to increase our knowledge of presettlement forest conditions and develop ways we can maintain and preserve oak areas on the Allegheny Plateau.

This project integrates several disciplines to answer these questions. Palynological analysis of bog sediments will identify changes in species composition over time as well as provide charcoal evidence of previous fire events needed for radiocarbon dating. Archaeology is providing information on Native American settlement and land-use patterns while witness tree analysis and historical data help to identify pre-European settlement forest conditions. We believe a study of this scope conducted in this region will provide some compelling information concerning Native American impacts on the forest resources of the Allegheny Plateau prior to European settlement.

STUDY AREA

The region comprises the Unglaciated High Allegheny Plateau characterized by broad flat-topped ridges deeply dissected by dendritic streams (Bowman 1911; Fenneman 1938). Soils are predominantly Inceptisols formed in residuum and colluvium from Mississippian and Pennsylvanian aged sandstones and shales (Cerutti 1985; Ciolkosz et al. 1989). Hazleton-Cookport soils occur on plateau uplands while Hazleton-Gilpin-Ernest soils dominate riparian sideslopes. Both are characterized as deep, well drained to moderately well drained, sloping to moderately steep soils formed from acidic sandstone and shale. Alluvial floodplains and glacial outwash terraces consist of Wayland-Chenango-Braceville soils and are characterized as deep, very poorly drained, level to gently sloping soils formed in water deposited materials derived from acid sandstone and shale (Cerutti 1985). Climate of the region is typified as cool and humid. Average temperatures range from 20û C in the summer to -2û C in the winter months. Total annual precipitation is 109 cm with 61 cm falling during the growing season between April and September (Cerutti 1985).

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PRELIMINARY RESULTS

Archaeological Evidence

Located within the study area are 55 pre-contact and 54 post-contact archaeological sites. Several included in the Buckaloons Historic District (BHD) are regarded as the most significant archaeological sites in Pennsylvania. Prehistoric artifacts from collections coupled with evidence from extensive field projects conducted within the study area suggest human occupation for the last 12,000 years. The area was first occupied by PaleoIndians during the retreat of the Wisconsin ice sheet between 12,000 to 11,000 y BP. As the ice retreated, Paleoindians advanced northward along the Allegheny River from the southern portion of Pennsylvania and Ohio following megafauna and other game (Funk 1993). It is widely held that seasonal hunting patterns operated on a north/south directional flow along major waterways. Vegetation composition and distribution changed as the glacial margin moved northward. Tundra-like conditions existed until around 12,000 y BP when replaced by open stands of spruce and by 10,500 y BP pine-oak forests dominated the landscape coinciding with increased charcoal abundance and a warmer, drier climate. These environmental changes certainly affected human resource collection and utilization. For instance, it is believed that by this period large megafauna such as the mastodon (*Mammut americanus*) had been extirpated and other mammals such as the caribou, moose, and deer comprised much of the diet of the inhabitants. Further, the collection of acorns, walnuts, and hickory nuts is recognized as another subsistence pattern of the Early Archaic period (Munson 1986).

A scarcity of Middle Archaic (c. 8000-6000 y BP) sites and artifacts indicates either a lower population in the area or that specialists have not been able to differentiate Middle Archaic artifacts from those of adjacent periods (Stewart and Kratzer 1989; Quinn and Adovasio 1996). The pollen record for western New York indicates a decrease in pine distribution and an increase in hemlock during this period (Trubowitz 1983). Although speculative, changes in species distribution may have affected faunal migration/population patterns thus impacting human migration/population patterns. However, by the Late-Archaic (6000-3000 y BP) northern hardwood and mixed oak forests dominated the landscape. At this time Peoples of the Brewerton and Lamoka cultures (Laurentian Tradition) inhabited the region. Brewerton peoples were adapted to the upland environments while the Lamoka peoples preferred riparian areas. Both cultures are characterized with hunting, gathering, and foraging subsistence strategies. Seasonal base camps have been identified on both the upland and riparian environments. Despite information concerning cultural developments, human-environmental interactions are not presently understood.

In northwestern Pennsylvania, agriculture developed during the Woodland Period (3,000-300 y BP) and was practiced extensively by the Seneca-Iroquois nation by 1350 AD (Dennis 1993; Snow 1994). The Iroquois practiced a form of swidden agriculture in which forests were cleared and burned to create open areas (Ketchum 1864; Parker 1968). Cultigens included the sunflower (*Helianthus annuus*), maize (*Zeas mays*), squash (*Curcubita* spp.), and beans (*Phaseolus vulgaris*) (Dimmick 1994; Snow 1994). Crops were cultivated in cleared fields extending out from a central village. Fields were cultivated for several years (8-12) until crop harvests decreased enough to warrant moving the village to another streamside site (Ritchie and Funk 1979; Sykes 1980, Snow 1994). The ability to raise crops reduced the dependence on hunting and gathering. In addition, agriculture was responsible for a sharp increase in population and development of a more sedentary existence evidenced by the development of large villages (Snow 1994).

Most occupation sites occurred on river or glacial outwash terraces and ranged in size from small clan hamlets of three or five longhouses capable of supporting 15-20 persons to villages encompassing ten longhouses on 8-10 acres supporting 150-200 people (Witthoft 1965; Ritchie and Funk 1979; Snow 1994). Nearly all Iroquois settlements were palisaded for protection (Snow 1994). These palisades consisted of large posts averaging one foot in diameter, with an upper limit of two feet (Ritchie and Funk 1979). According to the size of the village protected, constructing these defensive perimeters required a considerable amount of timber not to mention the quantity of fuelwood needed by the inhabitants.

Thus, over time, the anthropogenic landscape would resemble a mosaic pattern of (1) croplands near palisaded settlements, (2) abandoned clearings with early successional taxa, and (3) open forest stands dominated by fire adapted species such as oak and hickory (Chapman et al. 1982). Indeed, many paleoecological studies have identified a transition from later successional species to early successional species during the period of Native American burning and occupation (Chapman et al. 1982; Delcourt 1987; Clark and Royall 1995).

Witness Tree Analyses

Presettlement forest conditions were characterized by tallying corner trees from original warrant maps (1790-1820). Warrant maps represent a tract of land as surveyed at the time of first settlement (Munger 1991). Each warrant map comprises several bearings and distances linking property corners, either marked trees, posts, or stone monuments. After the tract was surveyed, a warrant map was produced illustrating the configuration of the lot, including boundary-line descriptions, property corners, whether trees or otherwise, and other outstanding geographic features such as streams, mountain peaks, or "Indian" paths (Abrams and Ruffner 1995). For this study, individual warrants and their corresponding witness corners were overlayed on USGS 7.5- min. quadrangle maps or identified on previously delineated boundary lines on USFS 7.5-min. quadrangle topographic maps. These connected drafts provided the main source for tallying the corner trees by species and physiographic landform (e.g. stream valley, north cove, plateau top, etc.).

Witness tree-topographic relationships were examined using contingency table analysis, a method which tests for

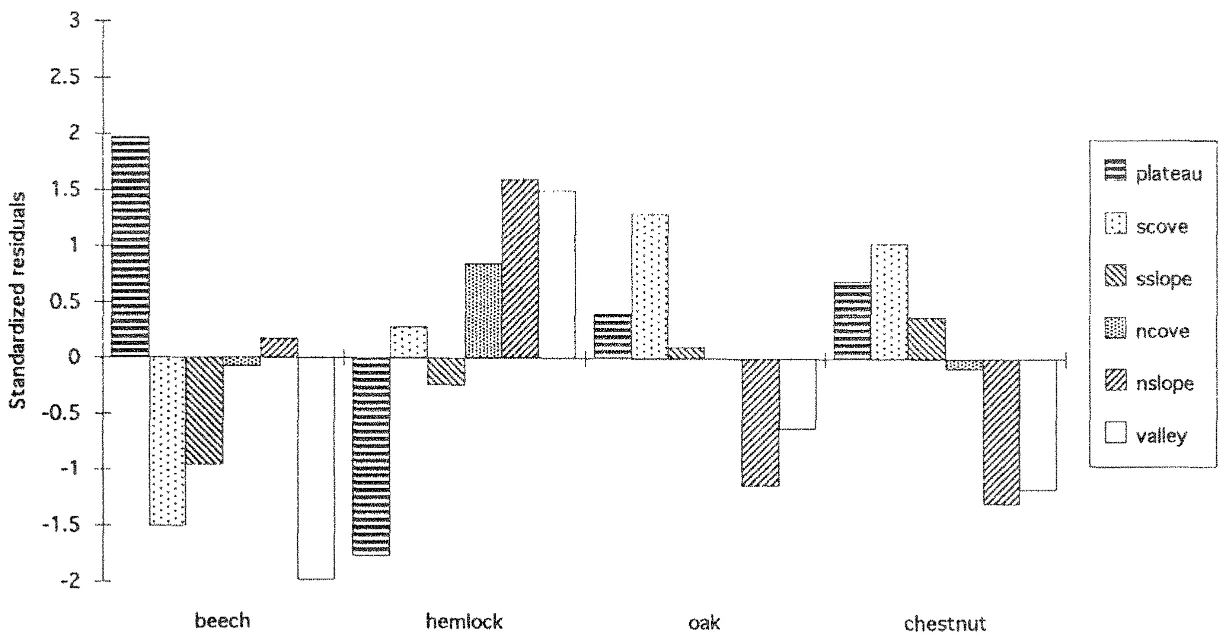

Figure 1.—Significant associations (p<0.01) of representative tree species on various landforms of the Allegheny Plateau. Positive and negative values indicate a preference or avoidance, respectively, for the landform.

independence between topographic position and the presence.abscence of a species (Strahler 1978). This test is performed by calculating the likelihood-ratio chi-squared statistic, G^2 and comparing this value to the appropriate quantile of the chi-squared distribution (Agresti 1996). Standardized residuals were calculated following Haberman's method (1973) for contingency tables revealing significance. Residual values quantify a species preference (positive) or avoidance (negative) of a particular topographic position (Whitney 1990).

Analysis of species-site relationships with standardized residuals provided some compelling information concerning species distributions on the Allegheny Plateau. When witness trees across the Allegheny Plateau were used, species distributions conformed nicely to current distributional conventions (Figure 1). For instance, American beech (*Fagus grandifolia* Ehrh.) dominated the plateau uplands while oaks and chestnut (*Castanea dentata*) dominated xeric, south facing slopes. Hemlock (*Tsuga canadensis*) in contrast, was cited most often on mesic slopes and valley/riparian sites.

Following this, witness tree distributions were separated into two zones, west and east of Minister Creek. This boundary was utilized because Minister Creek appears to be a major watershed roughly marking the edge of Native occupation east of the Allegheny River. Thus, witness trees were again tallied by site in these two regions, west and east of Minister Creek. Standardized residuals of species-site relationships reveals significant changes in species distributions (Figures 2 & 3). Ninety-three percent of all oaks and eighty-three percent of all chestnuts tallied occurred west of Minister Creek dominating the plateau uplands and south coves. In contrast, beech is limited to mesic slopes and is virtually absent from the upland plateau. Hemlock is relegated to mesic, protected cove sites. We believe this distinct shift in species on the uplands is a result of Native burning on these sites. Frequent burning would have selected for fire adapted species such as oak and chestnut with their thick fire resistant, corky bark. Further, archaeological sites occur more frequently in the oak-chestnut dominated uplands west of Minister Creek (Figure 4). Species distributions east of Minister Creek are very similar to those cited above for the Allegheny Plateau (Figure 3). Beech again dominates the upland plateaus while oak and chestnut numbers are limited to 6 (7%) and 7 (17%), respectively. We hypothesize that the level of disturbance, particularly fire, was reduced east of Minster Creek and thus late successional beech outcompeted oak and chestnut on the plateau uplands. Further, while some archaeological sites occur east of Minister Creek, they are not as widespread or frequent.

Historical Data

Historical documents such as explorer and missionary accounts, surveyor notes, military journals, and deeds are being searched for information concerning forest conditions and disturbances which may include for instance, Native fires, timber cutting, or agricultural practices. Thus far, early French explorers noted tall-grass prairies along the Irvine Flats of Brokenstraw Creek in Warren Township suggesting a portion of the prairie peninsula may have reached this area (Schenk 1887; Transeau 1935). In 1749, the French Government

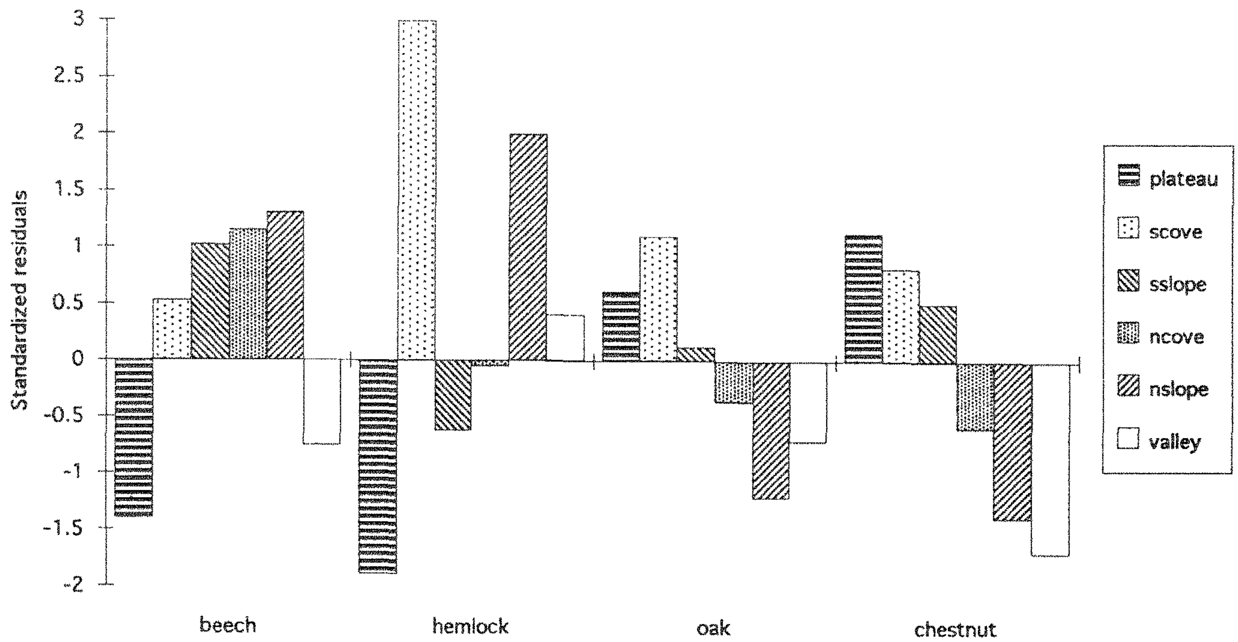

Figure 2.—Significant associations (p<0.01) of representative tree species on various landforms west of Minister Creek. Positive and negative values indicate a preference or avoidance, respectively, for the landform.

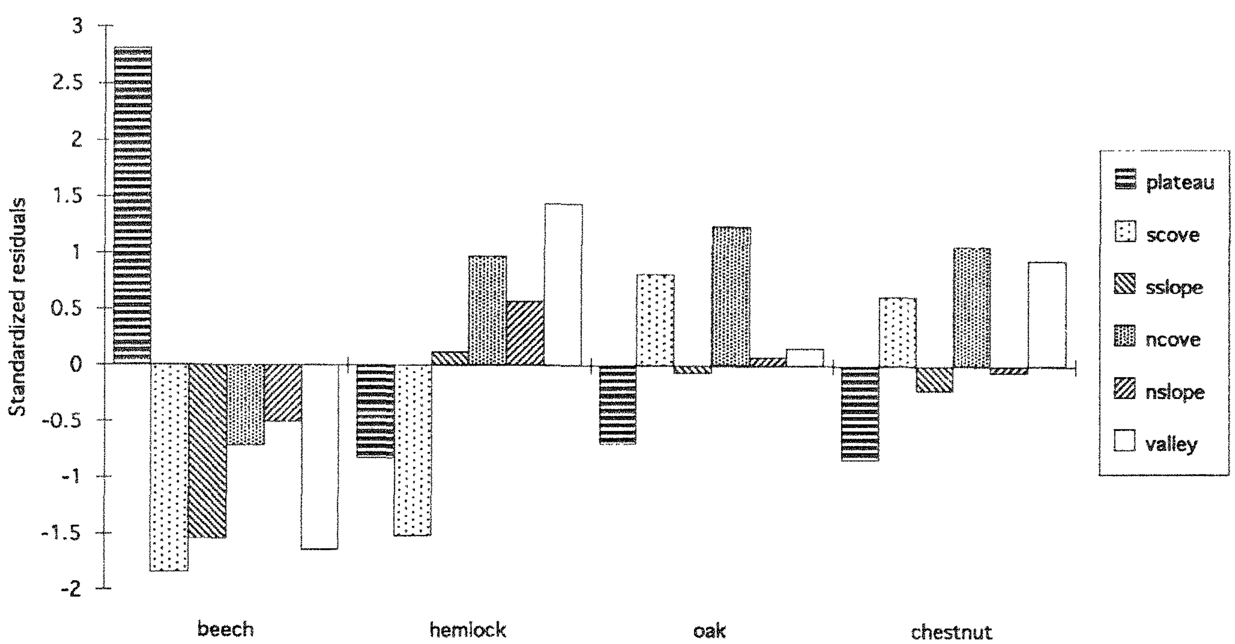

Figure 3.—Significant associations (p<0.01) of representative tree species on various landforms east of Minister Creek. Positive and negative values indicate a preference or avoidance, respectively, for the landform.

dispatched Captain Bienville de Celeron to officially claim the lands of the upper Ohio (Allegheny) River. While environmental information is sparse in these accounts, locations of Native villages are well described. Early travelers in western New York reported "oak openings" in areas previously inhabited by the Seneca (Ketchum 1864; Sagard 1865).

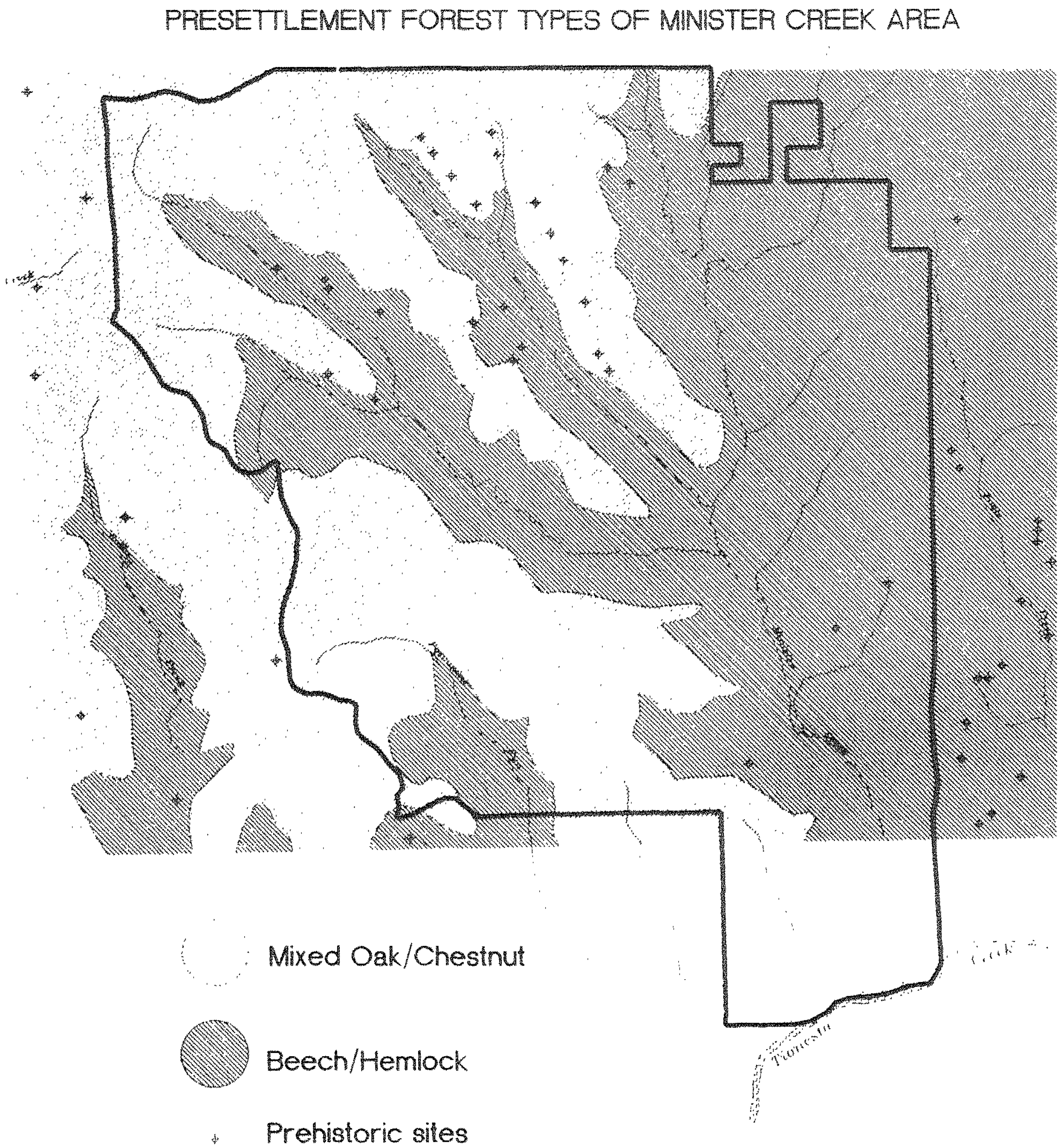

Figure 4.—Presettlement forest types of Minister Creek area with archaeological site distributions. Sites on east side of Minister Creek are camps exhibiting low intensity usage while sites on the west side are characterized by larger rockshelter complexes having extended histories.

Pollen Analysis

The basic assumption of pollen analysis is that the types of pollen depositied at a site represent the range of species growing in the area (Davis 1963; Fagrei and Iversen 1975). The large quantity of pollen mixing in the atmosphere before deposition is assumed to yield a pollen assemblage characteristic of the type of forest or other vegetation that produced the pollen (Kellogg and Custer 1994). Thus, changes in pollen frequencies through time represent changes in vegetation through time (Kellogg and Custer 1994). An exploratory bucket auger sample has been taken and is being analyzed for pollen preservation from the Jones Run bog. A sample from 1.4 m has been submitted for radiocarbon dating. The site appears to have the potential to yield a vegetation record spanning the last few thousand years. The basal unit is sand-gravel channel deposits, overlain by silt-clay overbank sediments, and capped by sphagnum peat—totaling about 1.5 meters of sediment.

FUTURE WORK

This project is essentially in the implementation stage and final results will not be available until the pollen analysis and archaeological excavations are complete. The authors have developed this study to assess the existence and extent of Native American impacts on natural resources of the Allegheny Plateau. We believe this integrative approach could be utilized in other regions to better understand the long term vegetational changes on the landscape and assess cultural adaptations or disturbances responsible for the anthropogenic landscape encountered by EuroAmericans during westward expansion.

LITERATURE CITED

Abrams, M. D. 1992. **Fire and the development of oak forests.** Bioscience 42: 346-353.

Abrams, M. D. and Nowacki, G. J. 1992. **Historical variation in fire, oak recruitment and post-logging accelerated succession in central Pennsylvania.** Bull. Torrey Bot. Club. 119: 19-28.

Abrams, M. D. and D. A. Orwig. 1996. **A 300 year history of disturbance and canopy recruitment for co-occurring white pine and hemlock on the Allegheny Plateau, USA.** J. Ecology 84: 353-363.

Abrams, M. D. and C. M. Ruffner. 1995. **Physiographic analysis of witness tree distribution (1765-1798) and present forest cover through north central Pennsylvania.** Can. J. For. Res. 25(4): 659-668.

Agresti, A. 1996. **An introduction to categorical data.** John Wiley and Sons. New York.

Bowman, I. 1911. **Forest physiography: Physiography of the United States and principles of soils in relation to forestry.** John Wiley and Sons. New York.

Braun, E. L. 1950. **Deciduous Forests of Eastern North America.** Hafner, New York. 596 pp.

Calkin, P. E. and K. E. Miller. 1977. **Late Quaternary environment and Man in western New York.** In: Amerinds and their paleoenvironments in northeastern North America. W. S. Newman and B. Salwen, (eds.) Annals of the New York Academy of Sciences, vol. 288: 297-315.

Cerutti, J. R. 1985. **Soil survey of Warren and Forest counties, Pennsylvania.** USDA Soil Conservation Service.

Chapman, J., P. A. Delcourt, P. A. Cridlebaugh, A. B. Shea, and H. R. Delcourt. 1982. **Man-land interaction: 10,000 years of American Indian impact on native ecosystems in the lower Little Tennessee River valley, eastern Tennessee.** Southeastern Archaeology 1(2): 115-121.

Ciolkosz, E. J., W.J . Waltman, T. W., Simpson, and R. R. Dobos. 1989. **Distribution and genesis of soils of the northeastern United States.** Geomorphology 2: 285-302.

Clark, J. S. and P. D. Royall. 1995. **Transformation of a northern hardwood forest by aboriginal (Iroquois) fire: charcoal evidence from Crawford Lake, Ontario, Canada.** The Holocene 5: 1-9.

Clark, J. S. and P. D. Royall. 1996. **Local and regional sediment charcoal evidence for fire regimes in presettlement north-eastern North America.** J. Ecology 84: 365-382.

Davis, M. B. 1963. **On the theory of pollen analysis.** American J. of Science 261: 897-912.

Davis, M. B. 1983. **Holocene vegetation history of the eastern United States.** In: Late Quaternary environments of the United States. H. E. Wright, Jr., (ed.) University of Minnesota Press, Minneapolis. p 166-181.

Day, G. M. 1953. **The Indian as an ecological factor.** Ecology 34: 329-346.

Delcourt, H. R. 1987. **The impact of prehistoric agriculture and land occupation on natural vegetation.** TREE 2: 39-44.

Dennis, M. 1993. **Cultivating a landscape of peace: Iroquois-European encounters in Seventeenth Century America.** Cornell University Press. Ithaca, NY.

DeVivo, M. S. 1991. **Indian use of fire and land clearance in the southern Appalachians.** In: Fire and the environment: Ecological and cultural perspectives. Nodvin, S. C. and T. A. Waldrop, (eds.) USDA For. Serv. Gen. Tech. Rep. SE-69.

Dimmick, F. R. 1994. **Creative farmers of the northeast: A new view of Indian Maize horticulture.** North American Archaeologist 15: 235-252.

Dincauze, D. F. 1987. **Strategies for paleoenvironmental reconstruction in archaeology.** In: Advances in Archaeological Method and Theory, Vol. 11. Academic Press, New York, NY.

Dincauze, D. F. and M. T. Mulholland. 1977. **Early and middle Archaic site distributions and habitats in southern New England.** Annals of the New York Academy of Science 288: 439-456.

Dorney, C. H. and J. R. Dorney. 1989. **An unusual oak savanna in northeastern Wisconsin: the effect of Indian-caused fire.** Am. Midl. Nat. 122(1): 103-113.

Fagrei, K. and J. Iversen. 1975. **Textbook of pollen analysis.** Hafner Press, New York.

Fenneman, N. M. 1938. **Physiography of eastern United States.** McGraw-Hill, New York.

Funk, R. E. 1993. **Archeological investigations in the upper Susquehanna Valley, New York State.** Persimmon Press. Buffalo, NY.

Gordon, R. B. 1940. **The primeval forest types of southwestern New York.** New York State Bulletin No. 321.

Haberman, S. J. 1973. **The analysis of residuals in cross-classified tables.** Biometrics 29: 205-220.

Hough, A. F. and R. D. Forbes. 1943. **The ecology and silvics of forests in the High Plateaus of Pennsylvania.** Ecol. Monogr. 13(3): 301-320.

Johnson, P. S. 1992. **Perspectives on the ecology and silviculture of oak-dominated forests in the central and eastern states.** USDA For. Serv. Gen. Tech. Rep. NC-153.

Kellogg, D. C. and J. F. Custer. 1994. **Paleoenvironmental studies of the State Route 1 Corridor: Contexts for prehistoric settlement, New Castle and Kent Counties, Delaware.** DelDOT Archaeology Series No. 114.

Ketchum, W. 1864. **History of Buffalo, with some account of its early inhabitants both savage and civilized.** Rockwell, Baker and Hill. Buffalo, NY.

Kuchler, A. W. 1964. **Potential natural vegetation of the conterminous United States.** Am. Geogr. Soc. Spec. Publ. 36.

Lorimer, C. G. 1985. **The role of fire in the perpetuation of oak forests.** In: J. E. Johnson, ed. Challenges in oak management and utilization. Coop. Ext. Serv. Univ. of Wisconsin-Madison, WI, 8-25.

Lutz, H. J. 1930a. **Original forest composition in north-western Pennsylvania as indicated by early land survey notes.** J. For. 28: 1098-1103.

Lutz, H. J. 1930b. **The vegetation of Heart's Content, a virgin forest in northwestern Pennsylvania.** Ecology 11: 1-29.

Maxwell, H. 1910. **The use and abuse of forests by the Virginia Indians.** Wiliam and Mary Quarterly 19: 73-103.

Meltzer, D. J. and B. D. Smith. 1986. **Paleoindian and Early Archaic subsistence strategies in eastern North America.** In: Foraging, collecting, and harvesting: Archaic period subsistence and settlement in the eastern woodlands. S. W. Neusius (ed.) Center for Archaeological Investigations Occ. Pap. No. 6.

Miller, N. G. 1973. **Late-glacial and postglacial vegetation change in southwestern New York state.** N.Y. State Museum Bull. 420: 1-102.

Morey, H. F. 1936. **A comparison of two virgin forests in northwestern Pennsylvania.** Ecology 17(1): 43-55.

Munger, D. B. 1991. **Pennsylvania land records: A history and guide for research.** Scholarly Resources, Wilmington, DE.

Munson, P. J. 1986. **Hickory silviculture: a subsistence revolution in the prehistory of eastern North America.** In: Proceedings, Emergent horticultural economies of the eastern woodlands. Southern Illinois University, Carbondale, Ill.

Nichols, G. E. 1935. **The hemlock-white pine-northern hardwood region of eastern North America.** Ecology 16(3): 403-422.

Parker, A. C. 1968. **Parker on the Iroquois.** W. N. Fenton, ed. SyracuseUniversity Press, Syracuse.

Patterson, W. A. III, and K. E. Sassaman. 1988. **Indian fires in the prehistory of New England.** In: Holocene human ecology in northeastern North America. G. P. Nicholas, ed. Plenum Publishing.

Pyne, S. J. 1983. **Indian fires.** Natural History 2: 6-11.

Quinn, A. G. and J. M. Adovasio. 1996. **1995 test excavations at 36WA132, Allegheny National Forest.** Mercyhurst Archaeological Institute. Erie, PA.

Ritchie, W. A. and R. E. Funk. 1973. **Aboriginal settlement patterns in the northeast.** New York State Museum Memoir 20. University of the State of New York, Albany.

Russell, E. W. B. 1983. **Indian-set fires in the forests of the northeastern United States.** Ecology 64: 78-88.

Sagard, G. 1939. **Father Gabriel Sagard: The long journal to the country of the Hurons (1632).** G. M. Wrong, ed. Publications of the Champlain Society, Toronto.

Schenck, J. S. 1887. **History of Warren County, Pennsylvania.** D. Mason & Co. Syracuse, NY.

Seishab, F. K. 1990. **Presettlement forests of the Phelps and Gorham Purchase in western New York.** Bull. Torrey Bot. Club. 117: 27-38.

Sirkin, L. 1977. **Late Pleistocene vegetation and environments in the Middle Atlantic region.** In: Amerinds and their paleoenvironments in northeastern North America. W. S. Newman and B. Salwen, (eds). Annals of the New York Academy of Sciences Vol. 288: 206-217.

Snow, D. R. 1994. **The Iroquois.** Blackwell Publishing, Cambridge.

Spear, R. W. and N. G. Miller. 1976. **A radiocarbon dated pollen diagram from the Allegheny Plateau of New York State.** J. Arnold Arboretum. 57: 369-403.

Stewart, M. and J. Kratzer. 1989. **Prehistoric site locations on the unglaciated Plateau.** Pennsylvania Archaeologist 59: 19-36.

Strahler, A. H. 1978. **Binary discriminant analysis: A new method for investigating species-environmental relationships.** Ecology 59: 108-116.

Sykes, C. M. 1980. **Swidden horticulture and Iroquoian settlement.** Archeology of Eastern North America. 8: 45-52.

Transeau, E. N. 1935. **The Prairie peninsula.** Ecology 16: 423-437.

Trubowitz, N. L. 1983. **Highway archaeology and settlement study in the Genesee Valley.** Occasional Publications in Northeastern Anthropology, No. 8.

Watts, W. A. 1979. **Late Quaternary vegetation of central Apalachia and the New Jersey coastal plain.** Ecol. Mono. 49: 427-469.

Webb, T. III. 1981. **The past 11,000 years of vegetation change in eastern North America.** Bioscience 31: 501-506.

Whitney, G. G. 1990. **The history and status of the hemlock-hardwood forests of the Allegheny Plateau.** J. Ecol. 78: 443-458.

Communicating the role of silviculture and Forest Service silviculture research in the Interior West.

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Abstract.—Silviculturists create desired forest conditions across the landscape and over time. Our job is to synthesize knowledge from many disciplines to develop prescriptions that produce desired forest conditions. In turn, forest conditions result in products and values for society. Silviculture and silviculture research help provide the scientific basis for land management decisions. Crucial roles for research silviculturists are mensurative studies that quantify resources, manipulative studies that test hypotheses, synthesis, and publication; without these, new knowledge will not be generated and the science of silviculture will progress slowly. Silviculturists are central to implementing Ecosystem Management, and they must communicate the importance of their profession to clients, other natural resource disciplines, policymakers, and the public. A checklist is provided highlighting important points about silviculture and silviculture research.

INTRODUCTION

The following is from an actual job announcement with a USDA Forest Service ranger district in the western United States.

Series/grade: GS-0460-11
Title: Forester (biomass administrator)
Duties: The incumbent serves as a silviculturist with primary responsibility for the development, planning, and application of silvicultural methods and practices.

The duties for this job are clearly that of a silviculturist, but the parenthetical title of biomass administrator suggests a reluctance to use the words silviculture and silviculturist. This job announcement is not an isolated case; rather, it reflects a trend to avoid the "S" word because of perceptions that silviculturists and the practice of silviculture are biased toward the single-minded production of wood products. Too many people think silviculture means tree culture.

At the same time, the profession is experiencing a decline in the number of silviculturists and research silviculturists in the Forest Service. Exact numbers are not available because silviculturists are included with foresters and research silviculturists are counted as research foresters. Nationwide over the past 10 years, the number of research foresters in the Forest Service has declined 61 percent from 350 to 138 positions (Stout 1996). In the Interior West[2], the number of research silviculturists declined 59 percent from 17 in 1980 to 7 in 1997 (Fig. 1). As Figure 1 shows, there has been a steady decline in research silviculturists.

Reduced numbers of silviculturists and research silviculturists brings several questions to mind. Is the vitality of the profession of silviculture in jeopardy? Have silviculture and silviculture research matured to the point that the number of people in the profession can be reduced? What is being lost when silviculture and silviculture research are de-emphasized?

The purpose of this paper is to discuss the role of Forest Service research silviculturists and their interactions with the profession of silviculture, land managers, the scientific community, and the public. The authors' perspective is shaped by working in the Interior West, but the situation may be similar in the rest of the United States. The points discussed in this paper can be used to communicate the role of silviculture and silviculture research to the many and varied publics that we all serve.

EVOLUTION OF SILVICULTURE AND SILVICULTURE RESEARCH

In the Interior West, the profession of silviculture has evolved for nearly 100 years from emphasis on individual trees to emphasis on the components and processes of forests. Silviculture research has prompted changes in silviculture and visa versa. Synergism between silviculture research and the practice of silviculture has advanced the art and science of the profession.

Early silvicultural practices in this country focused on individual trees because of their economic and social importance. Fernow (1916) defined silviculture as the production of wood crops. The economic production of wood for society was the goal of silviculture. Silviculture research investigated the silvics of commercial species, natural and artificial regeneration, tree growth, and relationships between the environment and tree growth. Research logically started with the emphasis on individual trees, but gradually there was increasing research on insects, diseases, fire, non-tree vegetation, soils, and other components of forests.

The advances in knowledge about silvical characteristics of species and growth of trees allowed emphasis to shift to stands of trees. Toumey (1928) and Baker (1934) expanded the definition of silviculture to include methods for establishment and development of forest stands for sustained production of wood crops. Now the emphasis was on stands of trees, but the goal was still wood production to benefit society. Silviculture research also expanded by conducting investigations at the stand level. Yield tables were developed for normal stands, as were stocking tables, thinning guides, and planting guidelines.

Next, silviculture was defined as the theory and practice of producing and tending a forest that best fulfills the objectives

[1]see appendix for author's affiliation
[2]Eastern Washington, eastern Oregon, Idaho, Montana, Wyoming, Utah, Colorado, Nevada, New Mexico, and Arizona.

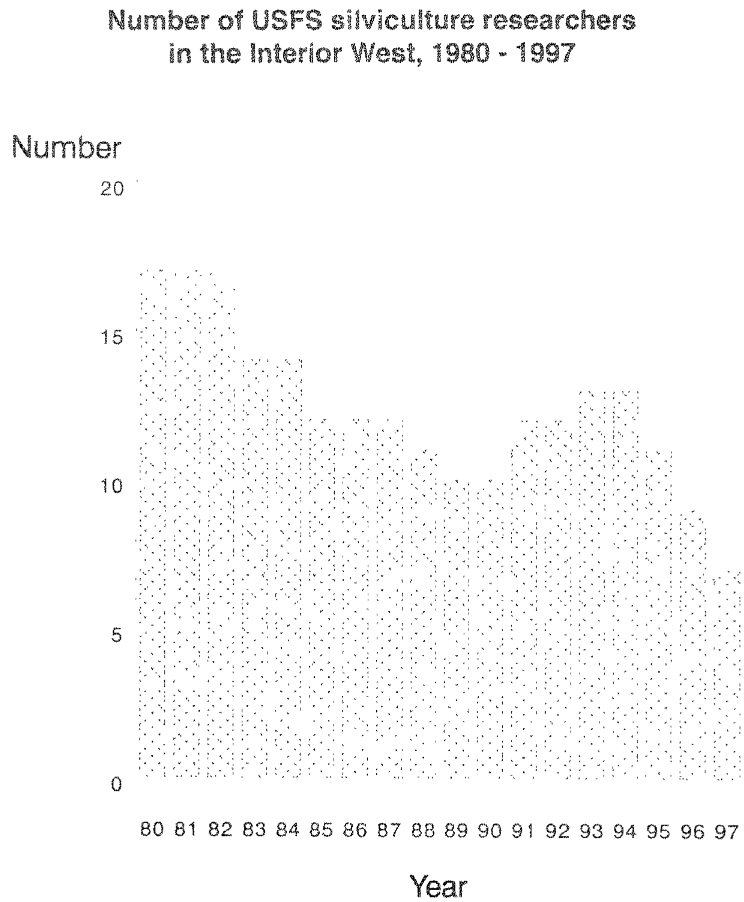

Figure 1.—Number of research silviculturists in the Interior West from 1980 to 1997.

of the owner (Smith 1962). It was no longer assumed that the landowner's objective was the production of wood. This important shift in emphasis recognized that landowners have a wide variety of objectives. Silviculturists developed prescriptions to meet many objectives, which could be as diverse as creating habitat for wildlife, providing clean water, or using genetically improved trees for wood production. The role of silviculture research expanded to use ecological community classifications (for example, habitat types and successional plant communities) that become available in the Interior West (Daubenmire and Daubenmire 1968; Pfister and others 1977; Wellner 1989). Forest growth models were developed, and they were being linked to models that predicted other forest attributes such as shrub cover, impact of insects and diseases, and wildlife (Edminster and others 1990; Moeur 1985; Stage 1973; Teck and others 1996). Silviculture researchers started integrating more ecosystem processes into their studies.

Today, silviculture is defined as "the art and science of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society on a sustainable basis" (SAF 1994). Silviculture is the management of vegetation and creation of forest conditions to meet landowner needs and objectives. Silviculture researchers now explore forest ecosystem processes, structures, and functions.

Where is silviculture in terms of its evolution? Interestingly, silviculture has progressed to meeting the intent of its original definition. The root word 'silva' is Latin for an area of woodland or forest (Glare 1968). The literal translation of silviculture is forest culture. Silviculturists prescribe management for all components of the forest to achieve a wide variety of objectives. The current evolution in silviculture to fully implement forest culture in the Interior West is possible because of the collective experience, tools, and scientific knowledge developed over the past 100 years.

CREATING DESIRED CONDITIONS

If silviculture is the art and science of controlling the establishment, growth, composition, health, and quality of forests and woodlands, how does the silviculturist influence the vegetation to meet needs and values? The answer is that vegetation is managed directly and indirectly to favor the desired outcomes. The kind, amount, intensity, and duration of vegetation manipulation depends on the objective.

Silviculturists create and maintain forest structures and processes that result in the desired forest conditions. Forest conditions result in products. Traditionally, products have been wood, water, wildlife, range, and recreation. Products can be easily quantifiable, like the traditional products, or products can be values such as biodiversity, scenery, and spiritual values. Today's silviculturists are dealing with a wide array of products that the public demands.

Silviculturists create desired conditions across the landscape and over time. They develop knowledge and tools for managing forest vegetation. The job of a silviculturist is to integrate knowledge from many disciplines (ecology, pathology, entomology, mensuration, wildlife, watershed, recreation, genetics, soil science, sociology, economics, and so on) to develop prescriptions that produce desired conditions. Not only are silviculturists skilled at creating desired conditions, they are also trained to understand how historic conditions have shaped current forests and how forests will change over time -- 10, 20, 50, and 100+ years into the future. This knowledge can help create desired conditions for today and for decades to come.

Silviculturists and silviculture researchers consider consequences of their actions in the short-term and long-term. Appropriate silviculture that creates desired short-term conditions may have undesirable long-term consequences. An example would be maintaining continuous tree canopy coverage in a scenic area. Short-term goals can be reached by using uneven-age management. Long-term results will be a shift in species composition from shade-intolerant species to shade-tolerant species. The species, amount, and quality of shrubs, forbs, and grasses will change. Associated with the shift to shade-tolerant species will be changes in animals, insects, fungi, and so on. These changes may be good or bad depending on the objective. Silviculturists communicate information about short-term and long-term consequences, describe alternatives, and develop prescriptions that best meet short- and long-term objectives.

VOLUNTARY AND INVOLUNTARY SILVICULTURE

An important point about little or no silvicultural management is that forests are involuntarily changed by human activity. A lack of planning for the future care, development, and replacement of forests becomes a kind of rudderless drifting (Smith 1962). Humans have changed natural cycles in forests, especially wildfires in the Interior West. Cultivation of land adjacent to forests and extinguishing wildfires have changed the frequency and intensity of fires. Human activity has also affected atmospheric CO_2, high altitude ozone, air temperatures, air quality, wildlife migration routes, gene flow, and the introduction of exotic species of insects, diseases, and plants. We cannot dismiss the existence of involuntary silviculture. It exists and it does have unintentional effects on forests.

Natural resource professionals must consider all consequences of alternative ways that forests can be managed. An example of clear thinking is the discussion about the supply and demand for wood, wood alternatives, and how local and national demand for wood is linked to global supplies (Dekker-Robertson, these proceedings). America is a net importer of wood and Americans use wood at a rate nearly 3.5 times the global average. Alternatives to wood (steel, aluminum, brick, concrete, and plastic) are expensive, consume large amounts of energy during the manufacturing process, and result in CO_2 release into the atmosphere. When demands for wood are not met locally or nationally, forests in other parts of the world are harvested. Ecologically sensitive tropical rainforests or forests in Siberia are much less productive than forests in the United States. In addition, environmental laws in many foreign countries are weak.

Even if the American people decided not to harvest wood from public lands, there are major health concerns for forests in the Interior West. Ecosystems are constantly changing; they do not and cannot remain static. More wood grows per acre per year in Interior West forests than can be decomposed by natural processes (Oliver and others 1994; Olsen 1963). The right combinations of moisture and temperature do not exist long enough each year for wood to decompose as fast as it grows. Fires, insects, and diseases are the disturbance agents that historically recycled excess biomass in the Interior West.

Large amounts of fuel are present in Interior West forests because of fire suppression efforts that began in the early part of this century. Forests that historically burned with low intensity ground fires are now experiencing stand replacing fires. Unacceptable loss of resources and lives are an added expense of fighting wildfires and rehabilitating burned forests. The choices are to manage forests before wildfires or after wildfires; doing nothing is an example of involuntary silviculture.

SILVICULTURISTS ARE INTERDISCIPLINARY GENERALISTS

Many of the disciplines in forestry are specialties that evolved from silviculture, so it is natural that there is a good deal of overlap between silviculture and other forestry specialties. For example, a forest entomologist must understand the habitat that supports insects and how that habitat influences life cycles, predators, hosts, and so on. But, silviculture is the one discipline where knowledge from many other disciplines is deliberately brought together to develop management prescriptions that meet owner's management objectives. Necessarily, a silviculturist is a generalist who must interact with others to develop the best possible prescriptions.

The integration of knowledge from many disciplines also means silviculturists work in an interdisciplinary manner with many people. Decisions concerning any one discipline in forestry cannot be made independently from other disciplines. Since most decisions will directly or indirectly involve vegetation management, the silviculturist is a key person on interdisciplinary teams. One job of the silviculturist is to help people understand the consequences of proposed alternatives. By collaborating with other disciplines, results of various alternatives can be described and displayed over time. Then, landowners can make more informed decisions.

THE ROLE OF FOREST SERVICE RESEARCH SILVICULTURISTS

The future is always uncertain; however, several things seem clear. The world's population is continuing to grow and people will increase their standard of living whenever possible. Current alternatives to wood are not as economical, are not renewable, and their production uses more energy and creates more pollution. Therefore, the demand for wood products will remain high. At the same time, greater demands are being placed on forests for other products such as clean water, wildlife, recreation, biodiversity, and forest health. The public expects science-based management of forests. Increasingly complex silvicultural prescriptions will be required to achieve multiple goals from forests.

Forest Service research silviculturists help envision and create the future forest under different management options. They need foresight to keep ahead of issues. Following are general areas of research in Interior West forests where silviculture research expertise is needed. Most of this research will require an interdisciplinary approach with researchers in mensuration, entomology, pathology, wildlife biology, social sciences, and so on. It will also require collaboration with user groups, universities, and other research organizations.

1. Forest development, naturally and with management.
2. Silvicultural systems for forest health and sustainability, and for resistance and resiliency to pests.
3. Management of biomass accumulation.
4. Silviculture for threatened and endangered plants and animals.
5. Silvics of previously unmanaged species.
6. Linking terrestrial and aquatic ecosystems.
7. Techniques and tools for communicating with each other and the public.

Forest Service silviculture researchers most often seek answers to applied, rather than basic, research questions. This pragmatic approach to research lends itself to close collaboration with user groups to identify research topics, conduct the research, and transfer research results into application.

The ability to conduct long-term research is a strength of Forest Service Research. There are two types of long-term research. First are studies where variables are remeasured over long time periods. Examples are measuring permanent sample plots, monitoring the flow of watersheds, and testing genetically improved trees. The second type of long-term research deals with a series of interrelated studies that must be conducted to gain knowledge about large, complex problems. For example, whitebark pine (*Pinus albicaulis*) is a keystone species in high elevation ecosystems. Seeds from whitebark pine are very important in the diet of grizzly bears (*Ursus arctos horribilis*), Clark's nutcracker (*Nucifraga columbiana*), and red squirrels (*Tamiasciurus hudsonicus*), but whitebark pine is being decimated by white pine blister rust (*Cronartium ribicola*). Research is needed to understand many things about whitebark pine, including more about silvics, reproduction, growth, nursery practices, planting methods, competition, genetic variability, and mechanisms of resistance to blister rust.

A relatively stable research program makes it possible to conduct both types of long-term studies. With stable funding, it is possible to plan and carry out long-term studies. Scientific and technical staffs provide continuity of research and safekeeping of records. But, long-term studies should be designed to give interim results that can be applied as soon as possible. Interim results are needed to help managers who must make decisions using the best available knowledge. Scientists working on both long- and short-term studies is a good balance.

Forest Service research silviculturists also conduct short-term studies very well. A trained and experienced workforce is well suited to conducting studies that can be complex and comprehensive. Forest Service research silviculturists also have opportunities to conduct research in a variety of ecosystems, which provides a breadth of knowledge and expertise.

The interaction among today's Forest Service silviculture researchers, colleagues, and clients is surprisingly complex. Studies are designed to answer complex questions about how biological systems function and how processes and structures interact. Collaborative efforts are essential to accomplishing the research. It is important that administrative boundaries do not impede cooperation among researchers because scientists need the freedom to pursue avenues of investigation that will provide answers to important management questions. The best collaboration begins at the grass roots level; generally a group of scientists and clients define a research need, decide upon a course of action, gather the necessary resources, and conduct the research. Grass roots collaboration needs to be protected and nurtured.

Forest Service research silviculturists have many clients. In the Interior West, users of Forest Service silviculture research include the Forest Service National Forest System, Forest Service State and Private Forestry, private industry, universities, state forestry departments, other Federal agencies, private landowners, Indian tribes, other scientists, environmental groups, and extension and consulting foresters. Research topics are chosen after consultation with clients, but research is not directed by user groups.

Independence of Forest Service silvicultural scientists is necessary. Autonomy is important because scientists are judged on their objectivity and independence to pursue the truth. While maintaining independence, silviculture researchers must work collaboratively with user groups to be familiar with their needs and to conduct high quality research. Unless scientific investigation is sustained, there will be no new technology to transfer (USFS 1995).

There are three main tasks in a Forest Service research silviculturist's job.

1. Scientific investigation.
2. Technology transfer.
3. Information and expertise.

Scientific investigation for a research silviculturist includes mensurative studies that quantify forest attributes (to answer "What is?"), manipulative studies that test hypotheses (to answer "Why?"), and synthesis of knowledge into recommendations (to communicate "How to"). Mensurative studies (Hurlbert 1984) provide information about forestry resources; for example, height-age relationships for regeneration or annual production of wildlife browse. Manipulative studies (Hurlbert 1984) that test hypotheses are crucial to explaining observed phenomenon and helping determine cause-and-effect relationships. Synthesis is a larger part of a research silviculturist's job than for other forestry disciplines. Research silviculturists integrate knowledge from many disciplines to develop and test systems, tools, and methods that can be used to meet a variety of goals. Integration requires a fundamental knowledge of many other disciplines.

Publication of research results is the most important step in technology transfer, but it does not stop there. Scientists make presentations at meetings, participate in field trips, and provide training. Demonstration areas also show results of research. Advances in technology such as videos and the Internet provide new ways of getting information to users.

Information and expertise is exchange of ideas and knowledge. Other duties of research silviculturists include consulting, special assignments, or involvement in inventory and monitoring. Consulting may be adapting knowledge gained in one ecosystem to another ecosystem, interpreting the accumulation of literature on a particular subject, or reviewing recommendations that are based on the scientist's research. Today's special assignments involve participating on assessment teams, writing management guidelines for threatened and endangered species, and helping implement ecosystem management.

The fundamentally important parts of a Forest Service research silviculturist's job are mensurative studies, manipulative studies, synthesis, and publication. If these tasks are not done, the science of silviculture will advance slowly. Mensurative studies quantifying biological relationships. Manipulative studies test hypotheses and help determine cause-and-effect relationships. Synthesis is the process of integrating new knowledge with existing knowledge and practices to develop improved management strategies. And, of course, research findings must be published so that the new knowledge is available to current and future generations.

CONCLUSIONS

The number of Forest Service silviculturists and silviculture researchers has steadily declined despite the need for both. Demand for products from forests will remain high because of expanding populations, rises in the standard of living, and increasing demands for a variety of products. The products from forests can be traditional products (wood, water, wildlife, range, and recreation), newer products (such as yew bark, mushrooms, and beargrass), or values (such as spiritual values, biodiversity, and forest health).

The profession of silviculture has a very important role in helping achieve the goals of forest management. The importance of that role must be communicated both internally and externally in a variety of ways and to a variety of publics. No one approach will reach the various publics because different groups have diverse knowledge about natural resources, forestry, and silviculture. However, the messages that need to be communicated are the same. Following is a listing of points about silviculture and silviculture research that are important to communicate to each other and the various publics we serve.

- Silviculture means forest culture. Silviculturists plan and implement treatments with all components of forest ecosystems in mind. Research silviculturists design research studies that consider all components of the forest.

- The choices are to silviculturally manage forests now or rehabilitate them later. This is especially true in the Interior West where wildfires, insects, and diseases have historically recycled accumulated biomass.

- Silviculturists realize that all forests are being managed because they are being managed either voluntarily or involuntarily. Involuntary silviculture occurs when there is a lack of planning for the care, development, and replacement of forests.

- Silviculturists are interdisciplinary generalists. Silviculture is the profession where knowledge from many disciplines is deliberately synthesized and applied.

- Silviculturists help achieve land management objectives. Objectives can be tangible products or less-tangible values.

- Desired conditions are created by manipulating vegetation to favor some species over other species. Conditions are created over time and across the landscape.

- The art and science of silviculture have co-evolved from growing trees, to stand management, to stand ecology, to landscape ecology.

- The profession of silviculture has accumulated enough tools, experience, and scientific knowledge to begin forest culture.

- And it is silviculturists who have the broad ecosystem-based training to do ecosystem management.

- Silviculture and silviculture research have short- and long-term perspectives. The consequences of short-term results must be considered in the context of long-term forest development.

- The fundamental roles of Forest Service silviculture research are mensurative studies, manipulative studies, synthesis, and publication. These four roles move the art and science of silviculture forward.

- Forest Service research silviculturists have many clients. Research topics are chosen in collaboration with clients, but research is not dictated by any client or user group.

Those of us in the profession of silviculture must be proactive in communicating the importance of silviculture and silviculture research. Good silvicultural practices will make people feel good about forestry and bring more credibility to natural resource management. Silviculturists *manage* to bring out the best from our forests.

LITERATURE CITED

Baker, F. S. 1934. **The principles of silviculture.** New York: McGraw-Hill. First edition. 502 p.

Dekker-Robertson, D. 1997. **Is the northern spotted owl worth more than the orangutan?**

Daubenmire, R.; Daubenmire, J. B. 1968. **Forest vegetation of eastern Washington and northern Idaho.** Wash. Agric. Exp. Sta. Tech. Bull. 60. Pullman, WA: Washington State University. 104 p.

Edminster, C. B.; Mower, H. T.; Mathiasen, R. L.; Schuler, T. M.; Olsen, W. K.; Hawksworth, F. G. 1990. **GENGYM: a variable density stand table projection system calibrated for mixed conifer and ponderosa pine stands in the Southwest.** USDA Forest Service Res. Pap. RM-297. 32 p.

Fernow, B. E. 1916. **Suggestions as to possibilities of silviculture in America.** Soc. Amer. Foresters Proc. 11:171-176.

Glare, P. G. W., ed. 1968. **Oxford Latin dictionary.** Oxford, Great Britain: Oxford at the Claredon Press. 2126 p.

Hurlbert, S. H. 1984. **Pseudoreplication and the design of ecological field experiments.** Ecological Monographs. 54:187-211.

Moeur, M. 1985. **COVER: a user's guide to the CANOPY and SHRUBS extension of the Stand Prognosis Model.** USDA Forest Service Gen. Tech. Rep. INT-190. 49 p.

Oliver, C. D.; Ferguson, D. E.; Harvey, A. E.; Malany, H. S.; Mandzak, J. M.; Mutch, R. W. 1994. **Managing ecosystems for forest health: an approach and the effects on uses and values.** J. of Sustainable Forestry. 2:113-133.

Olsen, J. S. 1963. **Energy storage and balance of producers and decomposers in ecological systems.** Ecol. 44:322-331.

Pfister, R. D.; Kovalichik, B. L.; Arno, S. F.; Presby, R. C. 1977. **Forest habitat types of Montana.** USDA Forest Service Gen. Tech. Rep. INT-34. 174 p.

SAF. 1994. **Silviculture terminology with appendix of draft ecosystem management terms.** Washington, DC: Society of American Foresters. 14 p.

Smith, D. M. 1962. **The practice of silviculture.** New York: John Wiley and Sons. Seventh edition. 578 p.

Stage, A. R. 1973. **Prognosis model for stand development.** USDA Forest Service Research Paper INT-137. 32 p.

Stout, S. L. 1996. **Where have all the silviculturists gone?** The Forestry Source. Washington, DC: Society of American Foresters. p. 10.

Teck, R.; Moeur, M.; Eav, B. 1996. **Forecasting ecosystems with the Forest Vegetation Simulator.** J. Forestry. 94:7-10.

Toumey, J. W. 1928. **Foundations of silviculture upon an ecological basis.** New York: John Wiley and Sons. 438 p.

USFS. 1995. **Navigating into the future. Rensselaerville roundtable: integrating science and policymaking.** U.S. Department of Agriculture, Forest Service. 14 p.

Wellner, C. A. 1989. **Classification of habitat types in the western United States.** USDA Forest Service Gen. Tech. Rep. INT-257. p 7-21.

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The Value of Long-term Silvicultural Research Studies

Wayne D. Shepperd and Carleton B. Edminster[1]

Abstract.—Reductions in research operating budgets and recent trends in research management philosophy have in many instances forced Forest Service scientists to realign their research programs to compete for short-term grants and other sources of funding. This approach may prove detrimental in silviculture, a discipline where long-term research is critical for: (1) research in the regeneration and establishment of forests, (2) testing management alternatives in established stands, (3) retaining research installations for future remeasurement; using them as laboratories for other disciplines, and adapting them to meet current and future needs. We present specific examples from our own experience where long-term studies have been utilized in these capacities.

INTRODUCTION

Neither of us confess to being dedicated followers of Forest Service policy, but our keen scientific minds and combined 50+ years of experience with the agency have enabled us to perceive what we consider to be disturbing trends in Forest Service Silvicultural Research. First of all, we've noticed that we simply don't have as much money to spend on our research as we once had. With smaller budgets, we can't afford to do large-scale experiments in a time of increased emphasis on landscapes and ecosystems. We have also noticed that a lot of our colleagues have disappeared too. We now compete with our academic friends in seeking soft money to fund research.

There are several changes in management philosophy within the Forest Service that have affected our discipline. There has been a movement away from commodity-oriented management with an accompanying emphasis on other resource values during the past few years. We are not suggesting that this has been wrong, but do wonder if the pendulum has swung so far that some basic principles of forestry have gotten trampled in the process.

Another contributing factor is the need for quick answers in today's crisis-to-crisis management environment. Managers simply don't have time to wait for the results of long-term studies to become available. As a result there is a perception that the need for silvicultural research has been reduced. The arguments for this position is that silviculture research is no longer pertinent to current management needs (e.g. we aren't growing timber anymore, we already know everything we need to know about growing trees, we need to learn more about ecosystems, etc.).

The scientific culture of rewarding scientists for the number of scientific publications produced is also detrimental to long term studies. Neither the scientist or the supporting agency are eager to initiate research efforts where investments are slow in producing rewards. This is especially true for scientists performing silviculture research where it may take years for trees to respond to treatment.

We feel that subscribing to these attitudes overlooks several critical issues. Trees are the defining component of forested ecosystems and we do still need to learn more about their biology, care and management. This is especially true as we seek new ways of maintaining and managing these ecosystems for purposes other than commodity production. For example, we know a lot about managing forests to produce wood fiber, but need to learn more about managing trees to maintain old growth, provide wildlife habitat, and reduce the risk of catastrophic disturbance in urban-interface and other high-value environments. We have learned much about the biology of tree species that have been utilized for wood products, but know little about many "non-commercial" species in our forests. We have well developed silviculture techniques for managing even-aged, single-species, forests, but need to refine un-even aged management techniques in mixed species forests and at landscape scales. The word "forest" is still in the name of the agency and as long as it is, we need to concern ourselves about trees as well as other natural resources.

Because trees are long-lived and grow slowly in some environments, silviculture is a discipline where long-term research is critical. Since the Forest Service has been managing trees for a long time and has established an infrastructure of facilities where long-term studies can be maintained, we feel Forest Service researchers are uniquely capable of conducting such studies. Our scientists have access to the largest network of experimental forests in the world, many of which have on-going studies that have been in place for decades. This gives us a tremendous advantage over our academic and industry colleagues, whose access to long-term study sites is limited, or driven by production forestry goals. We should not forsake these resources because of changes in public land management philosophy.

Our theme here is to remind our colleagues that silviculture is still a viable discipline, and that management of trees will still be done in the future. Although it may not be commodity-based as in the past, silviculturists are uniquely qualified and positioned to take the lead in planning and applying that management. Furthermore, we advocate that silviculture researchers should utilize existing and new long-term studies and installations to develop vegetation management techniques that can provide the attributes desired for our public lands.

DISCUSSION

Long term studies are critical to several areas of silviculture research and will be a key element to the development of

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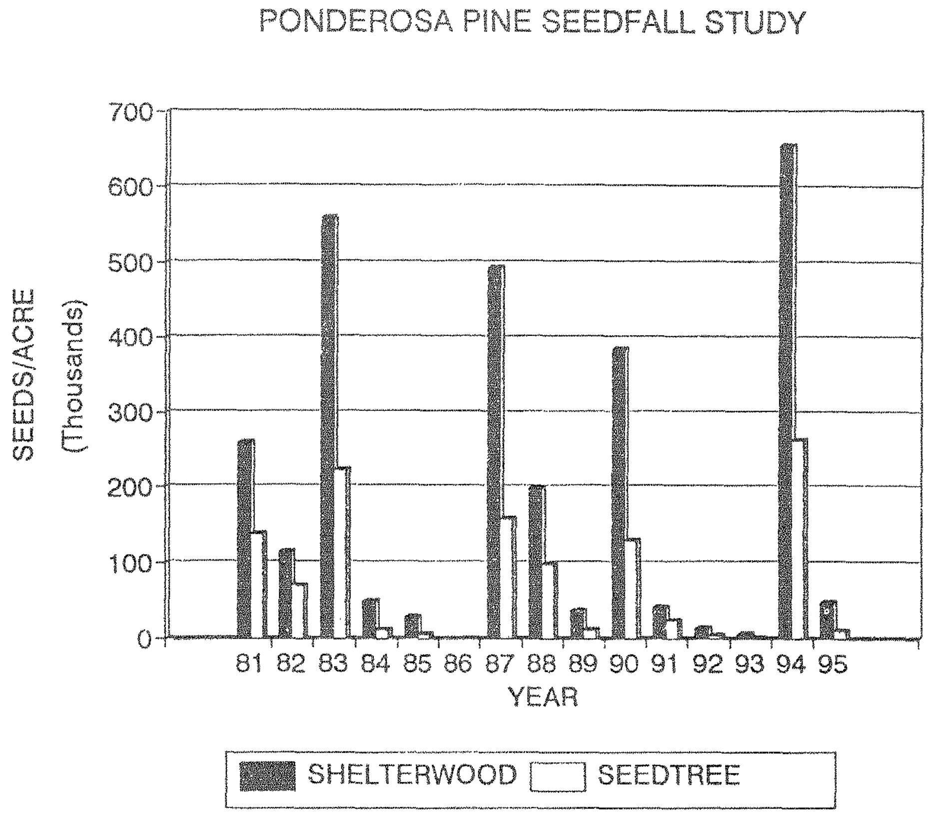

Figure 1.—Annual seedfall of Front Range ponderosa pine under shelterwood and seedtree overstories, 1981-1995.

new vegetation management techniques. For example, research in the regeneration and establishment of previously unmanaged species cannot be adequately done without long-term studies of the factors that influence growth and survival over time. No other method can furnish the necessary data. Similarly, long term studies are useful to test new management alternatives in established stands. Measuring growth responses to thinning and other density and structure control techniques over time is the only reliable way to collect the data needed to develop and refine growth and yield models. This kind of long-term research can be useful not only to forest management, but also to other disciplines such as basic ecological research. Long-term studies can provide data on tree biology that would be useful in developing process-based models in addition to growth and yield models. Long-term studies could also be useful in the science of developing monitoring protocols.

Our agency has adopted an adaptive management philosophy; a similar adaptive approach is needed in the management of long-term research installations. Retaining these research installations as field laboratories and adapting them to new uses is another way of utilizing these extremely valuable resources in answering new research needs. Installations that were established for one purpose can often be used for new research, with the existing data providing a critical historic reference to set the context of the new research.

To underscore the continued need for long-term research within our agency, we would like to present several examples from our own experience to illustrate how long term studies can meet these needs.

Manitou Experimental Forest Ponderosa Pine Regeneration Study

This study was established in 1981 to compare seed tree and shelterwood regeneration methods in Front Range ponderosa pine in Colorado. As part of the original study, we installed a grid of 900 seed traps and 450 6 x 6 ft. plots to monitor seedfall and seedling establishment. Fifteen years of monitoring have given us a very good picture of the periodicity of seedfall in Front Range ponderosa pine as well as a much better understanding of the growth and survival rates of natural pine seedlings. It is becoming increasingly apparent that good seed crops occur every 3-4 years in this environment, but usually not sequentially (Fig. 1) and that seedling survival follows a similar trajectory, regardless of the year of germination (Fig. 2). Our observations of differential seedfall and establishment from plot to plot have prompted us to initiate new research on the site to identify micro-climatic, soil, or topographic features that might be responsible. We have also mapped the position of overstory trees in an effort to identify and characterize those which produce consistently good seed crops. None of this research would have been possible using short-term studies.

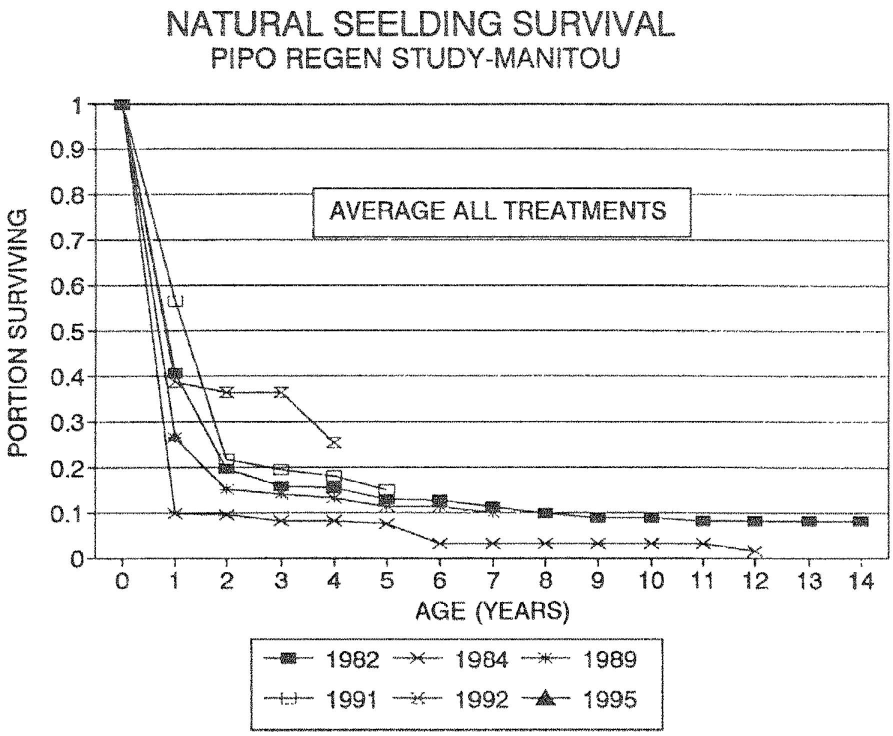

Figure 2.—Portion of ponderosa pine seedlings surviving to a given age, by year of germination.

Fraser Experimental Forest Engelmann Spruce Seed Production Study

This long-term regeneration study was installed in 1969 specifically to monitor seed production in natural high-altitude spruce stands (Alexander and Noble 1976). Although our continuous record of seed production is unique, perhaps the most valuable aspect of this study is the repeated inventory of the thirteen undisturbed old-growth stands surrounding our seed traps. This data will soon give us a thirty year record of mortality, recruitment, and growth in these stands. This study is an excellent example of adapting an existing long-term study for new, unanticipated uses.

Engelmann Spruce Provenance Plantation

This study was planted in 1970 as part of a national test of Engelmann spruce seed sources collected from throughout the natural range of the species (Shepperd and others 1981). Not only has the 25 years of survival and growth records given us valuable information about genetic variation within the species, it has also served as an excellent demonstration of the long-term value of using proper planting techniques at high altitudes. Following guidelines developed by former Rocky Mountain Station scientist Frank Ronco (Ronco 1972), we have achieved an overall survival of nearly 70%, 25 years after planting, and have clearly established that most mortality occurs in the first few years after planting. Such long-term quantitative planting records are unique in our experience and are invaluable in training new generations of reforestation specialists.

Fraser Experimental Forest Cutting Methods Study

Originally established to test and compare the efficiency of harvesting Engelmann spruce and lodgepole pine under even- and uneven-aged management, this study's most important role has been as a demonstration area where professional and lay visitors can view examples of correctly-applied silviculture, see first-hand the differences between even- and uneven-aged management, and discuss the benefits/trade-offs for other resources. It has been especially beneficial to natural resource professionals who do not have a forestry background. The uneven-aged sites have also benefited silviculturist trainees who can view diameter distribution Q curves applied on-the-ground.

The Fort Valley Experimental Forest Levels of Growing Stock Study

This ponderosa pine research was initiated to study the effects of stand density management on the development of second-growth stands. The Taylor Woods installation at Fort Valley Experimental Forest near Flagstaff, Arizona, is the oldest of four similar installations west-wide. The area at Taylor Woods was commercially harvested in winter 1923-24 and contained an understory of saplings established in 1914 and smaller seedlings established in 1919. This aspect of the study certainly qualifies as research in the regeneration and establishment of forests and illustrates the value of having long-term data from a site.

The second-growth stand that developed from these saplings was initially thinned by Gilbert Schubert in 1962 (Schubert

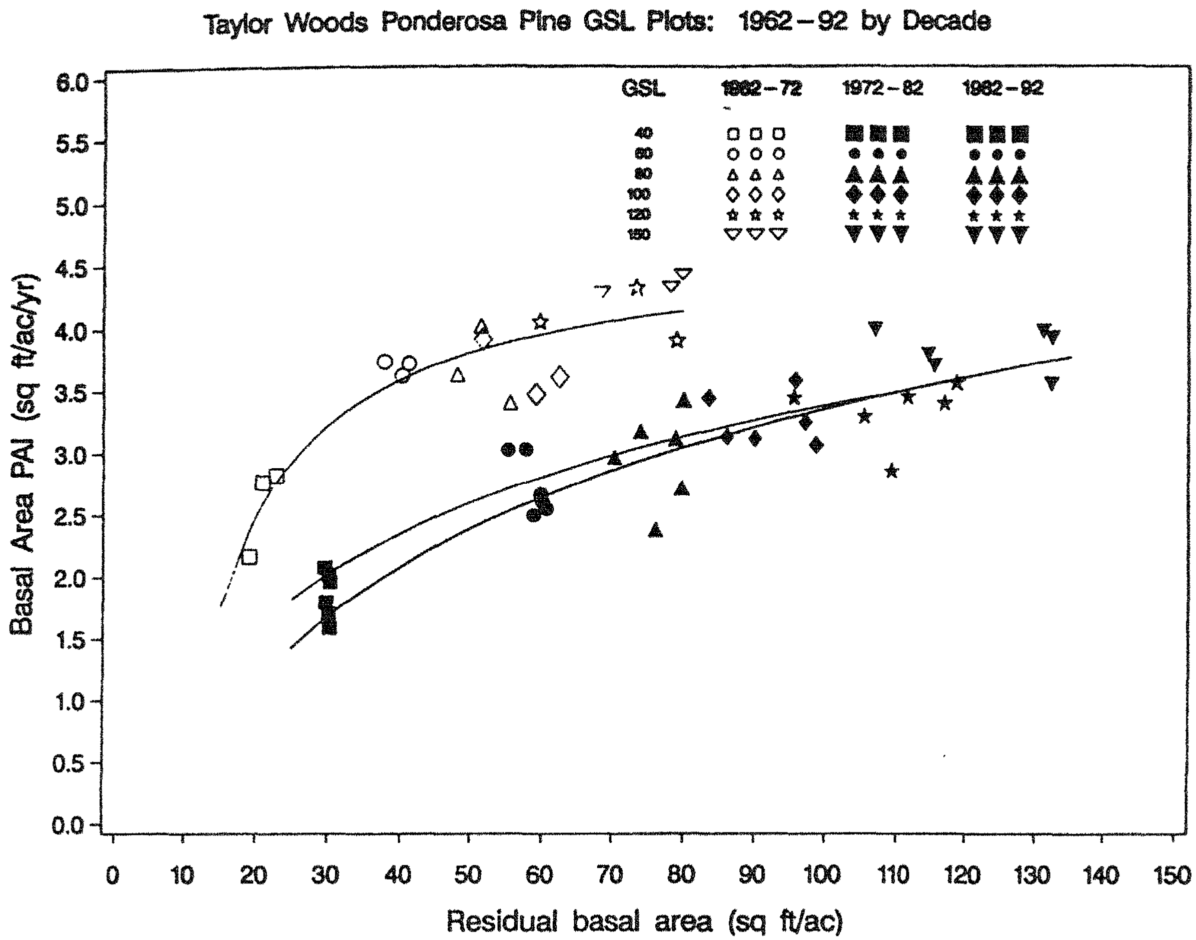

Figure 3.—Basal area growth by growing stock level (GSL) calculated prior to thinnings at 10, 20, and 30 year intervals, Taylor Woods levels of growing stock study.

1971) under a study plan written by Clifford Myers (both former RM scientists). All the large trees remaining after the 1923-24 cut were harvested in the early 1960's, prior to the study initiation.

Basal area annual growth rates varied by stand density as would be expected, but growth also varied for each 10-year remeasurement period after thinning (Ronco et al. 1985). Note how the growth was different during the initial period showing an adjustment to growing space after the first thinning, and fairly consistent during the next two periods (Fig. 3). This is an excellent demonstration of why permanent installations are a most effective tool for researching and demonstrating long-term stand dynamics. A ten year study would have given much different results that the thirty-year study has revealed.

Taylor Woods has not only been a test of management alternatives. It is also an excellent example of how long-term research installations can be retained as field laboratories and adapted to new uses. Taylor Woods has been used to study the effects of density management on wood quality of harvested trees, mushroom production as a food source for Abert's squirrels, understory herbage production, resin production and photosynthetic rates, and canopy cover. While there has been a shift away from even-aged management in the Southwest, the study provides an excellent example of how the rates of tree development can be controlled by managing stand density to obtain variability in tree sizes in even-aged forests. Standing and discussing the real thing is better than a conference room any day. Permanent research installations are critical demonstration areas and an important communication tool for both research and management.

North Kaibab Ranger District Group Selection Study

This recent study installation for uneven-aged management of ponderosa pine on the North Kaibab Ranger District, Arizona is an example of how we envision long-term studies might be continued in the future. It seeks to determine the effects on stand dynamics when an unregulated large-tree component is retained with a group selection cutting method at various residual density levels, such as would be done for wildlife habitat. In this study, large-tree groups have been retained, where in traditional uneven-aged management many would have been harvested. The study will provide basic information on growth rates of smaller trees, such as those regenerated from a previous group selection treatment in the study site. In addition, the study is also investigating the effects of prescribed burning on the survival and growth of residual trees of all sizes, future regeneration establishment, and snag longevity.

By sharing resources and a study design such collaborative long-term research efforts are more cost effective than single discipline studies. In addition to research funding, Timber Management and the Kaibab N.F. also contributed funding and resources to facilitate plot establishment and treatment. Research collaborations such as the Kaibab study give silvicultural researchers the resources to provide leadership in adaptive management. Providing the site and resources to help establish this study has given Forest personnel a vested interest and feeling of ownership and responsibility for this study. This is extremely important in maintaining long-term studies, especially those established off experimental forests. Such partnerships are critical to the success of our research program and we advocate their use elsewhere.

CONCLUSIONS AND RECOMMENDATIONS

We feel that long-term silviculture research is an investment that pays real dividends over time. It will be beneficial for the Forest Service to continue to do long term research as public land management policy evolves. Our experience with the studies we have discussed here has convinced us that our agency has a unique advantage over other research organizations in that we have access to the facilities, control of the land, and the continuity of personnel to engage in such studies. Long-term studies have always been a key part of the Forest Service's research program. We feel they should be retained, adapted and strengthened in the future to meet our agency's changing information needs.

LITERATURE CITED

Alexander, R. R.; Noble, D. L. 1976. **Production of Engelmann spruce seed, Fraser Experimental Forest: A 5-year progress report.** Res. Note RM-324. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4p.

Ronco, F. Jr. 1972. **Planting Engelman spruce.** Res. Pap. RM-89. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 24p.

Ronco, F. R.; Edminster, C. B.; Trujillo, D. P. 1985. **Growth of ponderosa pine thinned to different stocking levels in northern Arizona.** Res. Pap. RM-262. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 15 p.

Schubert, G. H. 1971. **Growth response of even-aged ponderosa pine related to stand density levels.** J. For. 69:857-860

Shepperd, W. D.; Jeffers, R. M. Ronco, F. Jr. 1981. **An Engelmann spruce seed source study in the central Rockies.** Res. Pap. RM-231. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 5p.

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

Chris Nowak, Susan Stout, John Brissette, Laura Kenefic, Gary Miller, Bill Leak, Dan Yaussy, Tom Schuler, and Kurt Gottschalk[1]

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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[2]Unpublished document on file, Northeastern Forest Experiment Station, Director's Office, Radnor, PA.

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

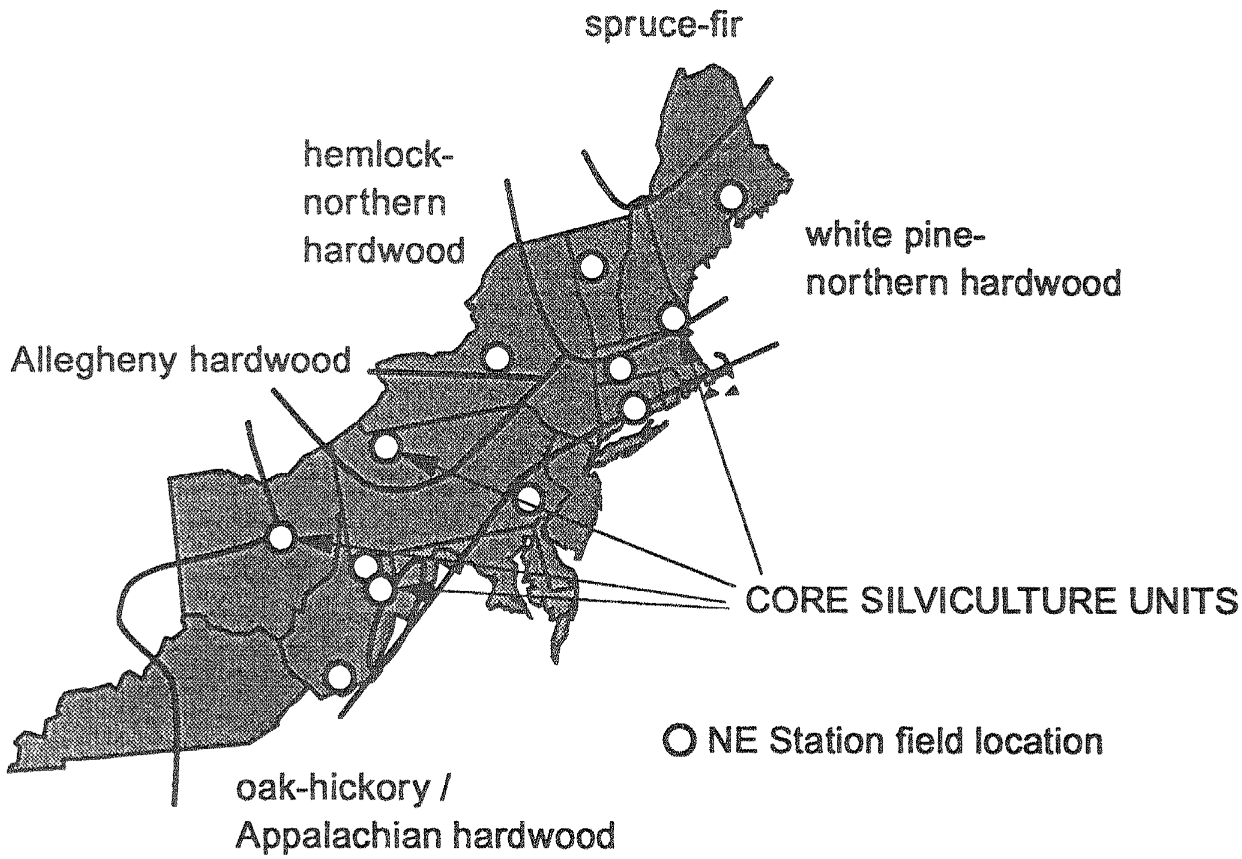

Figure 1.—Location of core silviculture research work units across the Northeastern Forest Experiment Station, with reference to associated major forest types.

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

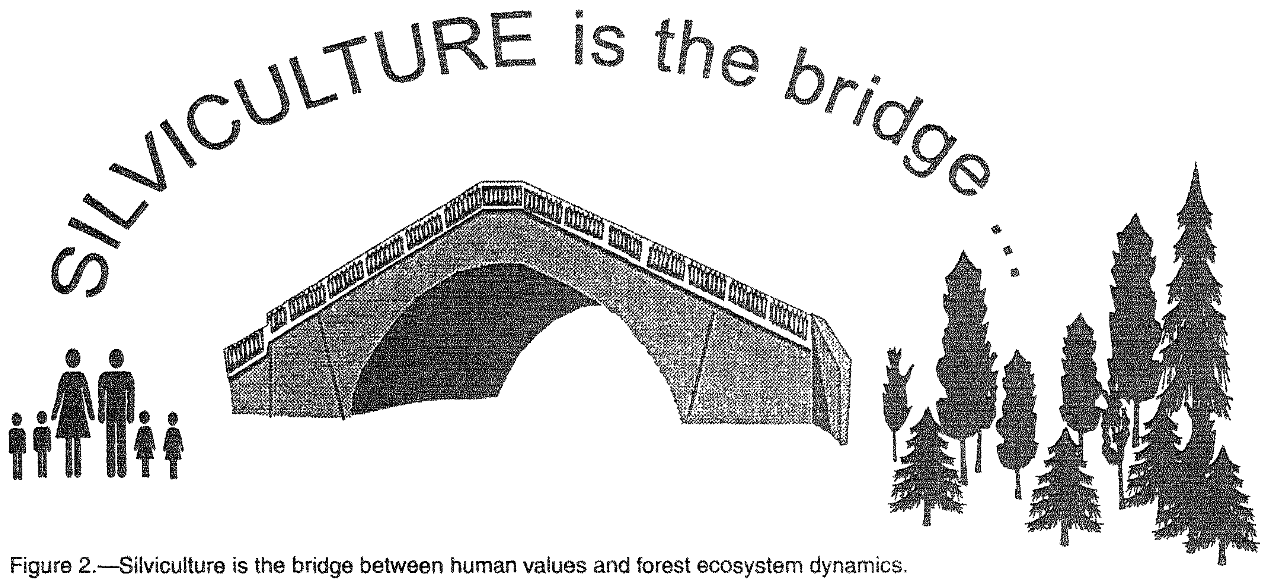

Figure 2.—Silviculture is the bridge between human values and forest ecosystem dynamics.

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.

Two-Age Silviculture on the Monongahela National Forest—Managers and Scientists Assess 17 Years of Communication

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Abstract.—This report describes the development of two-age silviculture on the Monongahela National Forest and provides an assessment of the practice as it is applied today. Silviculturists at each ranger district provided a chronology of the communication process between managers and scientists that led to current stand treatment prescriptions. In addition, data were collected from a total of 20 recently treated stands on four ranger districts. This information was used to assess two-age systems in terms of current stand conditions and the implications for future species composition and stand structure. Comments obtained from land managers and the accompanying field data are used to illustrate how the ongoing communication process helped to provide feedback, clarify objectives, motivate useful research, define feasible options, and produce a flexible land management tool.

INTRODUCTION

For many years, clearcutting was an important silvicultural practice for harvesting and regenerating new stands of central Appalachian hardwoods on the Monongahela National Forest (MNF). Public opposition to the visual impacts of clearcutting led land managers to seek alternatives that provide adequate light and seedbed conditions for tree regeneration, but are more aesthetic after cutting while the new stand becomes established (Smith and others 1989). Since 1991, clearcutting has been prescribed on a decreasing number of acres on the MNF and is being replaced in part by two-age silvicultural systems, alternative regeneration methods that show promise in sustaining multiple forest benefits such as aesthetics, species diversity, high-quality wood products, and habitat for many wildlife species.

This paper describes an ongoing partnership between land managers on the MNF and scientists at the Northeastern Forest Experiment Station (NEFES) that led to the expanded use of two-age silvicultural systems to meet emerging management objectives. First, background information is provided to clarify silviculture terminology and to chronicle the history of two-age silviculture as it has been applied on the MNF. Second, the process of communication between managers and scientists is summarized to demonstrate a possible model for others to use in developing and implementing innovative silvicultural practices. Third, results from a recent study of 20 two-aged stands located throughout the MNF are provided to illustrate the current status of this practice in three forest cover types.

BACKGROUND

Two-aged stands resemble those treated with a seed-tree or shelterwood practice in that a given number of overstory trees are retained while all other trees are cut (Fig. 1). However, to maintain a two-age stand structure, the residual trees are not cut once the reproduction becomes established as in even-age practices. Instead, the harvest of the residual trees is deferred until new reproduction is between 40 and 80 years old, generally one-half to a full sawtimber rotation. The result is a two-age stand structure. Once the two-age stand structure is established, similar practices can be repeated at intervals of 40 to 80 years to maintain this condition for many years. Management of some stands on the MNF is based on a 200-year rotation, so two-age cuts could be applied several times per rotation.

Silviculturists use several terms to describe regeneration methods that effectively create a two-age stand structure. These terms include deferment cutting, clearcutting with reserves, shelterwood with reserves, and irregular shelterwood. Deferment cutting and clearcutting with reserves are used to describe practices in which residual trees are retained for an entire sawtimber rotation to achieve goals other than reproduction. The other terms describe practices in which residual trees are retained to achieve goals other than regeneration, but not necessarily for an entire rotation. Thus, the terms used to describe two-age regeneration methods are defined by how long the residual trees are to be retained. In practice, residual trees can be retained for different periods of time to achieve different goals. For this reason, two-age silviculture is a general term that describes a host of regeneration methods designed to maintain and regenerate a stand composed of two distinct age classes that are separated by more than 20 percent of the planned rotation.

Silvicultural systems that promote a two-age stand structure have been initiated on national forests, state forests, industrial forests, and to a lesser degree on nonindustrial private forests in many eastern states. A similar practice called "insurance silviculture" was applied in Pennsylvania to retain a seed source in the event of a regeneration failure (Bennett and Armstrong 1981). The reasons for using two-age silvicultural methods are twofold: to regenerate a variety of species, particularly those that are shade-intolerant, and to mitigate the perceived negative visual impacts of clearcutting. Similar to clearcut stands, natural regeneration that follows two-age regeneration methods includes a variety of both shade-tolerant and shade-intolerant commercial hardwoods (Trimble 1973; Miller and Schuler 1995). Unlike

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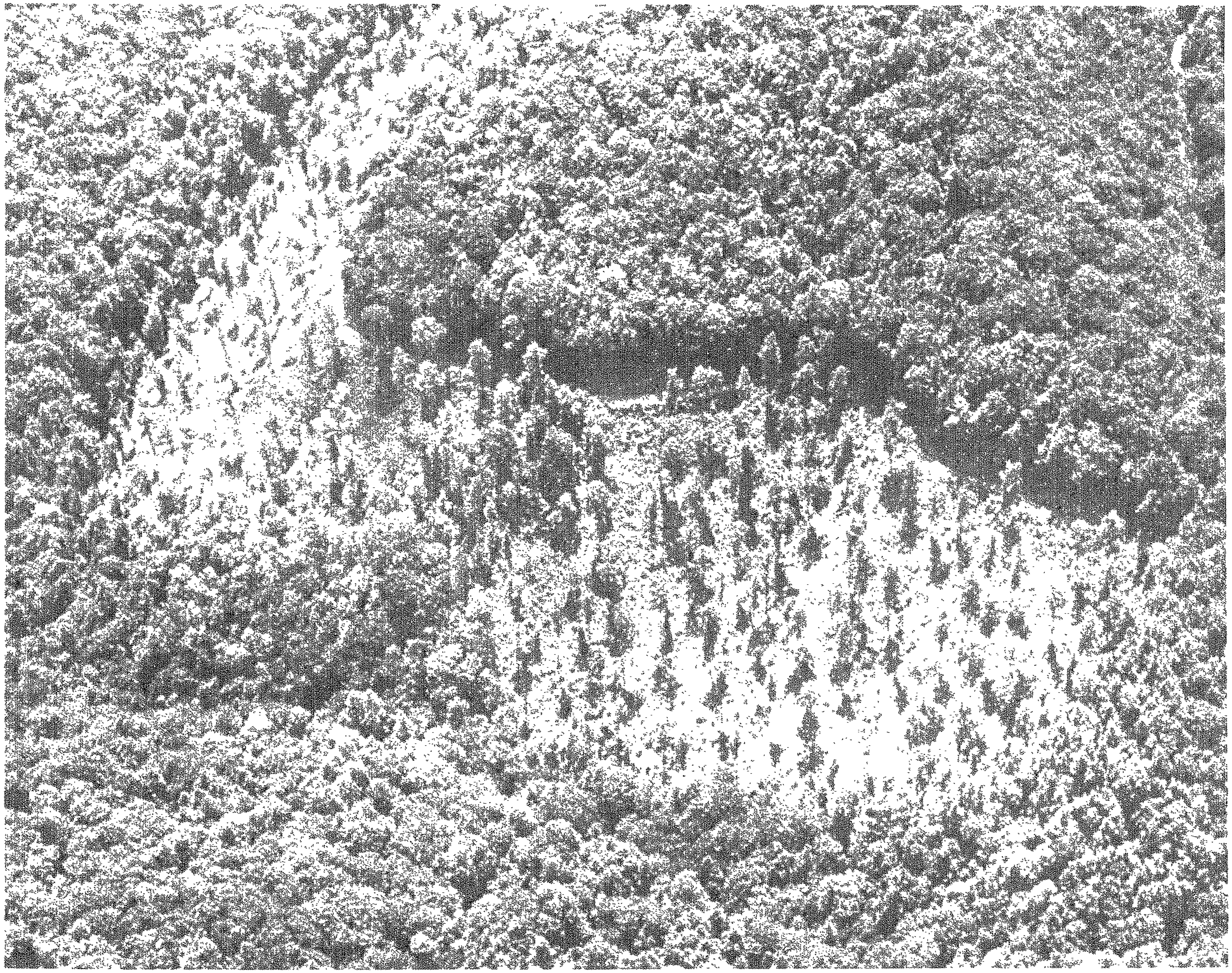

Figure 1.—A two-aged central Appalachian hardwood stand 3 years after treatment.

clearcutting, however, the presence of residual overstory trees improves aesthetics and maintains a more diverse vertical stand structure that may benefit certain wildlife species (Pings and Hollenhorst 1993). As the new cohort develops beneath the large overstory residuals, the stand has two distinct height strata. These strata provide a diverse habitat for songbirds that forage in high canopy trees (Wood and Nichols 1995), as well as those that require a brushy cover characteristic of a young even-aged stand (DeGraaf and others 1991). Two-age silvicultural practices also provide an opportunity to retain species that produce hard mast for wildlife food.

Early History

During the 1970's, forest managers on the MNF began considering alternative regeneration methods in response to public criticism of clearcutting. An employee of the USDA Forest Service visited Europe and learned of deferment cutting, a two-age regeneration practice used to manage larch, pine, and oak-beech stands (Kostler 1956; Troup 1966) to improve the aesthetics of even-age practices that remove the overstory over a relatively short interval. In 1979, an experimental deferment cut was applied on the Greenbrier Ranger District in cooperation with NEFES scientists at Parsons, West Virginia. Five additional experimental deferment cuts were applied on the Cheat and Marlinton Ranger Districts and the Fernow Experimental Forest by 1983. These study sites, which range from 10 to 15 acres, have since provided preliminary silvicultural information on two-age regeneration methods for forest managers who are interested in alternatives to clearcutting.

After the experimental deferment cuts were applied, the study sites served as valuable demonstration areas where students and forest managers from the forest industry and various public agencies were able to see two-age silviculture in action. As these two-aged stands developed through the 1980's, preliminary reports were published on residual tree growth and the development of regeneration (Beck 1986; Smith 1988; Smith and others 1989). In addition, forest managers on the MNF were able to visit these stands over the course of several growing seasons to monitor the progress of the new reproduction and to evaluate their potential as an alternative to clearcutting.

Recent History

In 1990, a team was organized on the MNF to define and evaluate possible alternatives to clearcutting. This team included experts from many disciplines: wildlife biology, landscape architecture, silviculture, and forestry research. Two-age management was included as a viable alternative for regenerating shade-intolerant species and improving aesthetics. The first operational two-age cuts were applied on the Potomac and Greenbrier Ranger Districts in 1991. These stands also served as demonstration areas for managers from other districts.

Since then, clearcutting has been prescribed on a decreasing number of acres. Since 1990, regeneration treatments were prescribed on an average of 1,500 acres/year on the MNF. The proportion of acres on which clearcutting was prescribed declined from 98 to 45 percent from 1990 to 1995. In most situations, two-age regeneration treatments were prescribed instead of clearcutting, and this trend is expected to continue.

In 1995, personnel from the MNF, NEFES (Parsons, WV), and Northeastern Area State and Private Forestry (Morgantown, WV) collaborated on a Marker Training Workshop for timber marking crews on the MNF. Silviculturists and marking crews from each district attended a 2-day training session that focused on proper residual stand stocking levels and criteria for identifying leave-trees to meet various management objectives. This workshop included hands-on marking exercises in various forest cover types. An important result of this workshop was that the concerns of district silviculturists, specialists from non-timber disciplines, and administrators on the forest were included in the marking guidelines. As a result, timber marking became more consistent throughout the forest, and marking crews were better prepared to implement the intended prescriptions.

The process of evaluating two-age practices and improving application methods on the MNF is continuing. The aesthetics of residual stands were compared to those resulting from other silvicultural methods (Pings and Hollenhorst 1993). A study of songbird density and nesting success in two-aged stands was conducted from 1992-1996 (Wood and Nichols 1995; Miller and others 1995). Logging economics and product market options also have been investigated (Miller and Baumgras 1994; Baumgras and others 1995). New studies are planned to develop improved methods for increasing the proportion of oak regeneration that develops before and after two-age cuts are applied.

COMMUNICATIONS

The following sections describe highlights in the ongoing partnership between land managers and scientists that led to increased use of two-age silviculture as an alternative to clearcutting on the MNF. The first two sections describe how management objectives and stand treatment prescriptions evolved during this process, followed by recommendations from forest managers for future research needed to improve the effectiveness of two-age regeneration methods. Finally, some suggestions on useful communication tools are offered that might assist other forest management partners in developing and implementing innovative silvicultural practices.

Defining Forest Management Objectives

An important first step in the development of two-age silviculture on the MNF was to narrowly define the problem and to clarify the management objectives so that specialists from a variety of resource management disciplines could work toward a common end. Initially, the problem was defined as the need for practical alternatives to clearcutting. The objectives were to identify alternative regeneration methods that provide for adequate desirable regeneration after harvest operations and improve the aesthetics of treated stands compared to clearcutting.

A range of regeneration methods was evaluated based on their effectiveness in providing the light and seedbed conditions necessary to regenerate desirable species, while improving the post-harvest aesthetics compared to clearcutting. In evaluating potential alternatives, additional management objectives became apparent. For example, group selection, which results in small clearings (0.5-2.0 acres) where desirable regeneration can develop and aesthetics are improved compared to clearcutting, is a viable alternative. However, this alternative would require a dramatic increase in the number of sale acres to regenerate the same number of acres as would be possible through clearcutting. Another objective for alternative harvest methods called for silvicultural practices that would not involve sale acres beyond practical limits. While group selection is a sound silvicultural practice, other regeneration methods (in addition to group selection) were needed to address concerns about sale acreage.

The implications for wildlife habitat also were considered in evaluating potential alternatives to clearcutting. Several options such as seed tree, shelterwood, and two-age practices, which entail the retention of residual trees, were recognized as improvements over clearcutting because residual trees provide mast, dens, perches, and habitat for foraging and nesting for many wildlife species. Moreover, two-age practices were superior because residual trees are retained for a relatively long time compared to seed tree and shelterwood practices. As a result, improved wildlife habitat also emerged as one of the management objectives used to define suitable alternative harvest methods.

As resource management specialists and scientists worked toward defining a suitable alternative to clearcutting, various silvicultural options also were evaluated in terms of their potential effect on Forest Plan goals and management prescriptions. For example, each alternative was evaluated in terms of its effect on recreation, aesthetics, harvest volumes and acreages, and economics. The interaction among the various resource specialists, scientists, and administrators that occurred during this process resulted in a valuable exchange of ideas and a more integrated approach to land management that continues today. Through this process, land managers at the district level became better prepared to prescribe stand treatments that account for many management objectives involving multiple forest resources.

Stand Prescriptions Then and Now

Based on information provided by forest managers at each of the ranger districts, stand prescriptions for two-age regeneration methods have changed since 1991 as individual silviculturists build on their experience with this relatively new practice. The initial prescriptions called for residual basal areas ranging from 20 to 40 ft^2/acre, with the residual stand composed of mostly sawtimber trees (Smith and Miller 1991). Actual residual stocking levels after harvest operations were greater than intended because marking crews were accustomed to leaving more trees as is done in thinnings or selection cuttings. There also was a tendency to remove most of the larger, high-quality sawtimber and retain the smaller, low-quality sawtimber and poletimber. This was due in part to the perceived risk of grade loss, logging damage, or grade reductions from epicormic branching to residual trees during and after harvest operations.

As silviculturists and marking crews on the districts gained more experience with this practice, and additional information about the response of residual trees was provided by scientists, stand prescriptions have changed accordingly. In general, the more recent stand presciptions reflect an increased emphasis on enhancing the long-term species composition of the regeneration and quality of the residual trees. More recent prescriptions require lower residual stand density, ranging from 20 to 30 ft^2/acre with about 15 to 20 sawtimber trees/acre. These prescriptions also call for cutting all other stems 1.0-inch d.b.h. and larger. Lower residual densities are more favorable to the reproduction of desirable shade-intolerant species, particularly over long periods of time when crown expansion of residual trees may interfere with reproduction. Current prescriptions also call for leaving larger, high-quality, long-lived sawtimber trees because vigorous codominant trees are less likely to die or suffer grade loss after treatment than trees in weaker crown positions (Miller 1996).

Guidelines for choosing residual trees to improve wildlife habitat also have improved as forest managers gain experience with two-age regeneration methods. This improvement is the result of continued interaction among personnel of several resource disciplines, since the first two-age cuts were applied on an experimental basis in 1979. Desirable residual trees for mast production include American beech, black gum, hickory, and the oaks. For example, white oaks are preferred residual trees for wildlife and timber because they are long-lived and produce acorns for a relatively long time. For habitat diversity, residual trees also include cull trees with large cavities, standing dead trees, and conifers such as hemlock, pines, and spruces.

Research Results and Future Needs

Two-age regeneration practices were applied on an experimental basis in six central Appalachian hardwood stands on the MNF and the Fernow Experimental Forest from 1979 to 1983. These areas ranged from 10 to 15 acres on site index 70 and 80 for northern red oak and provided preliminary results on the growth and development of the residual overstory trees and the species composition and quality of reproduction that became established after the treatments were applied. Such results were shared with silviculturists on the MNF over the years and later published. The following sections provide a brief review of research results that were helpful in developing stand prescriptions in use today, followed by a summary of new research that forest managers need for the future.

A Review of Research Results

D.b.h. Growth.—In general, residual trees after two-age regeneration harvests exhibited faster diameter growth compared to control trees in uncut stands over the 10-year study period, though growth response varied by individual species (Miller and others 1995) (Table 1). Residual trees were free-to-grow with an average crown growing space of 20 feet to adjacent residual tree crowns after treatment (Miller and Schuler 1995). Control trees also were codominant, but they had crown competition on all sides during the study period. For black cherry, average d.b.h growth of untreated controls exceeded that of released trees, though the difference was not statistically significant (P = 0.48). For all other species tested, released trees had greater average d.b.h. growth compared to that for control trees.

Table 1.—Ten-year d.b.h. growth for central Appalachian hardwoods released by deferment cutting versus unreleased controls

Species	Treatment	Number of trees	Initial d.b.h.	10-year d.b.h. growth	P[a]
			- - - - - - *Inches*	- - - - - -	
White oak	Release	59	14.5	2.89	<0.01
	Control	14	19.6	1.02	
Chestnut oak	Release	12	14.4	2.18	0.13
	Control	6	17.2	1.57	
Red oak	Release	200	16.7	3.34	<0.01
	Control	58	19.9	1.92	
Yellow-poplar	Release	193	17.8	3.65	<0.01
	Control	46	17.3	1.95	
Black cherry	Release	66	14.2	2.30	0.48
	Control	47	16.9	2.21	
Basswood	Release	18	15.1	2.93	<0.01
	Control	9	18.6	1.47	

[a]P= probability of a larger F for 10-year growth; analysis of covariance means adjusted for initial dbh.

D.b.h. growth of released trees was 45 to 134 percent faster than controls, led by white oak, yellow-poplar, basswood, and red oak. White oak, chestnut oak, red oak, and basswood grew faster the second 5 years compared to the first 5 years after treatment. For yellow-poplar, residual trees grew faster during the first 5 years after treatment, though growth during the second 5 years continued to exceed that of controls.

Survival and Quality of Residual Trees.—A total of 667 residual trees were monitored for survival and quality after two-age cuts were applied (Miller 1996). After 10 years, 89 percent of residual trees had survived. A total of 6 trees (1 percent) were destroyed or removed due to inadvertent damage during logging. After logging, 22 trees (3 percent) died within 2 years, and an additional 38 trees (6 percent) died between the 2nd and the 5th year. Mortality after the 5th year was greatly reduced; only an additional 7 trees (1 percent) died by the end of the 10th year. Mortality was greatest for black cherry (more than 20 percent), least for yellow-poplar (less than 5 percent).

The risk of residual trees developing new epicormic branches increases as the intensity of the cut increases (Trimble and Seegrist 1973). Epicormic branching increased for all species within 2 years after two-age cuts compared to pretreatment levels. Between year 2 and 10 there was no significant increase in the number of epicormic branches on the butt 16-foot log sections. Epicormics continued to increase on the second 16-foot log section for black cherry, red oak, and yellow-poplar. The net effect on quality was that 12 percent of residual trees exhibited a reduction in grade (Hanks 1976) due to new epicormic branches over the 10-year study period. Of the few grade reductions observed, white oak, northern red oak, and black cherry were most susceptible, while less than 1 percent of yellow-poplar trees had lower grades due to epicormic branching.

Logging operations resulted in bark wounds (exposed sapwood) on about one-third of residual deferment trees. Half of wounded trees had wounds less than 50 in^2, and half had larger wounds. Most of the wounds were located on the lower portions of the bole and were caused by skidding logs too close to residual trees. More than 95 percent of logging wounds that were less than 50 in^2 in size callused over and were closed within 10 years after logging. Based on the observed rate of closing over a 10-year period, Smith and others (1994) estimate that larger wounds up to 200 in^2 in size will close within 15 to 20 years after logging.

Reproduction.—Reproduction observed after two-age cuts was similar to that observed after clearcutting (Miller and Schuler 1995). Before two-age cuts were applied, small reproduction (less than 1.0 inch d.b.h.) averaged 3,019 stems/acre, with 50 percent in shade-tolerant species (maples and American beech), 37 percent in shade-intolerant species (black cherry and yellow-poplar), and 13 percent in intermediate-shade-tolerant species (oaks and white ash). More than 80 percent of survey plots (0.001-acre) had at least one commercial hardwood species present, and more than 60 percent of survey plots had sugar maple or American beech present.

Two years after harvest, small reproduction (< 1.0 inch d.b.h.) in the study areas averaged 9,100 stems/acre of commercial species composed of 60 percent seedling-origin stems. There also were more than 14,000 stems/acre of noncommercial woody species. More than 95 percent of survey plots had a commercial stem present. Five years after harvest, the canopy of the new age class developing beneath the residual overstory had not closed. Large woody reproduction ($\geq$ 1.0 inch d.b.h.) after 5 years included more than 300 stems/acre of commercial species and 100 stems/ acre of noncommercial species.

After 10 years, the canopy of the new age class developing beneath the deferment trees was nearly closed, and codominant trees averaged 35 feet tall. Large reproduction included 991 stems/acre of commercial species, with 450 good, codominant stems/acre exhibiting the potential to become high-quality crop trees in the future. On excellent growing sites, northern red oak reproduction was sparse, averaging only 10 potential crop trees/acre. Other codominant, commercial species reproduction included a variety of both shade-tolerant and shade-intolerant species distributed over 74 percent of the stand area.

Songbird Density and Nest Success.—Songbird density and nest success in clearcut and two-aged stands were compared 10 years after cutting treatment (Miller and others 1995; Wood and Nichols 1995). Songbird density estimates were greater (649 vs. 522 birds/ 40 ha; $P< 0.001$) in the two-aged stands. Interior-edge (359 vs. 320 birds/40 ha; $P<0.001$) and edge (83 v. 12 birds/40 ha; $P<0.001$) species were more abundant in two-aged stands. The abundance of interior species was similar (207 vs. 190 birds/40 ha; $P >0.10$) for two-aged and clearcut stands, respectively. Nest survival (151 nests) was not significantly different between the two-age and clearcut treatments (50% vs. 54%; $P>0.10$), and predation by mammals was the most common cause of nest failure.

Future Research Needs

As silviculturists on the MNF gained experience in prescribing two-age regeneration treatments and considered the implications of such practices for the future, the following questions arose.

Harvesting systems and economics.—For unconventional logging operations based on cable and helicopter systems, what is the optimal pattern of residual trees to minimize logging cost and damage to residual trees? How do local markets influence the cutting cycle and product mix for harvests in two-aged stands? How can two-age regeneration methods be applied in stands where there is limited merchantable volume and value?

Regeneration.—How does residual stand density and structure affect species composition and quality in the future? What silvicultural treatments are needed before two-age cuts are applied to increase the reproduction of target species such as northern red oak? How does the logging system and season of logging operations affect reproduction? What impact do residual trees have on the genetics of reproduction in the future? What impact do deer have on reproduction?

Residual trees.—How does increased diameter growth affect tree quality for veneer products? How do logging wounds affect the quality and vigor of residual trees? How do tree age and species affect growth, survival, and seed production? What is the rate of crown expansion for residual trees of different species?

Non-timber Issues.—How do two-age stand structures affect aesthetics in middle-ground views (0.25-4 miles)? How do residual tree species, vertical structure, and density affect aesthetics? How do aesthetics change as the new stand develops and vertical structure becomes more diverse? How do residual stand structure and density affect songbirds, small mammals, and game species over time?

As two-age regeneration methods are used to meet emerging forest management objectives, additional research is needed to better understand the implications of this innovative practice. It is important to define linkages among abiotic and biotic ecosystem components that may be affected by maintaining two vertical strata of woody vegetation over extended periods of time. For example, additional studies are needed to determine the relationship between stand density and structure on game and nongame wildlife communities. And because the forest is always changing, more research is needed to define the susceptibility of residual trees to attacks by insects and pathogens over much longer time periods. This practice may also affect product options in the future. Residual trees grow rapidly after two-age regeneration cuts, and such growth rates may influence product quality and utilization options.

Suggested Communication Tools

Land managers and scientists utilized several communication tools during the last 17 years to improve and develop two-age stand management prescriptions. The following suggestions are four possible strategies that might be helpful to others who are considering the use of unconventional silvicultural methods: the use of demonstration areas, holding meetings in the field, conducting forest-wide training sessions, and sharing preliminary information.

The stands in which experimental two-age cuts were applied served as valuable demonstration areas for sharing information. Initially, forest managers had the opportunity to evaluate the general appearance of a two-aged stand and ask important questions about the long-term implications of such treatments. The initial visits prompted numerous questions about the fate of residual trees and the new reproduction. As a result, the demonstration areas challenged land managers and scientists to better understand the implications of two-aged stands. As the stands developed, these areas also provided a medium for presenting and interpreting preliminary results.

The demonstration areas were located throughout the forest on three ranger districts, so forest management personnel had "ownership" and were able to visit these areas and monitor development with minimal investment of time and expense. Later, these areas served as a place to hold meetings, train personnel, and educate the public about the objectives of two-age silviculture. Thus, it is important that demonstration areas are accessible and inexpensive to visit for maximum impact on communications.

Another successful communication strategy entailed holding meetings among resource specialists, district silviculturists, and the forest leadership team in the field, against the backdrop of one or more of the demonstration areas. These sessions were two-way exchanges of questions and answers for personnel at different levels of management. The outdoor forum promoted an open dialog of ideas and reduced confusion about the management objectives and/or the long-term implications of using two-age regeneration methods. In particular, such meetings were an efficient use of time because participants usually could direct their questions and answers to tangible issues such as epicormic branching on residual trees, characteristics of forest roads, or vertical structure of the residual stand that are visible on the site. In addition, scientists often were invited to such meetings to provide updated research results and to stay abreast of new research needs.

The forest-wide training for marking crews helped to make two-age stand treatment prescriptions more consistent across the forest. Marking crews and silviculturists from all districts had the opportunity to interact with each other through hands-on marking exercises in the field. Participants practiced selecting residual trees, asked questions of each other, and resolved confusion about management objectives associated with two-age systems. These activities clarified the criteria for selecting residual trees for a range of objectives. As a result, the 2-day training session prepared each marking crew to better implement a stand prescription as intended by the silviculturist.

Scientists also made an effort to share preliminary research information with land managers as it became available. This was accomplished through preliminary written reports (before the formal publication of results), telephone conversations, and field visits to the demonstration areas. Obtaining preliminary research results at frequent intervals helped the silviculturists make more rapid progress toward developing appropriate stand prescriptions. Similarly, presenting such information and obtaining feedback helped the scientists focus on the high-priority needs of the land manager. This exchange of preliminary information is ongoing.

There also are opportunities to communicate the implications of innovative silvicultural practices through existing channels within the Forest Service. For example, two-age silviculture is now part of the Program of Advanced Studies in Silviculture (PASS) throughout Regions 8 and 9. At the forest level, the forest planning process provides an opportunity to involve outside groups in fine-tuning the objectives of silvicultural treatments, which in turn clarifies guidelines for writing stand treatment prescriptions.

Table 2.—Percent of trees reduced in grade due to logging wounds or epicormic branching after deferment cutting[a]

Species	Small sawtimber (12-16 inches d.b.h.)				Large sawtimber (18 inches d.b.h. and larger)			
	n	Number of trees	%	95% CI[b]	n	Number of trees	%	95% CI
Yellow-poplar	23	1	4	<1-34	11	0	0	0-46
Black cherry	59	3	5	<1-11	38	3	8	1-22
Northern red oak	43	2	5	<1-19	32	1	3	<1-16
White oak	19	0	0	0-20	9	1	11	<1-48
Chestnut oak	22	0	0	0-11	15	0	0	0-33
Sugar maple	61	4	7	<1-12	20	0	0	0-17
Red maple	49	1	2	<1-12	10	0	0	0-49
White ash	41	4	10	<1-18	20	0	0	0-17
American basswood	17	0	0	0-26	3	0	0	0-71

[a]Data from 20 stands on the MNF where operational two-age cutting was applied.
[b]95% confidence interval.

ASSESSMENT OF CURRENT PRACTICES

In 1996, data were collected on 20 two-aged stands on the MNF that had been treated two to five growing seasons before the study. This survey was conducted to assess current conditions and to shed light on the implications of two-age cutting on future species composition and wood product quality. Thus, the results presented here on residual tree response and reproduction are preliminary findings that do not necessarily represent the long-term implications of this practice (Johnson and others 1997).

Residual stand quality

A total of 768 individual trees representing nine commercial species were evaluated for tree grade (Hanks 1976), epicormic branches, and logging damage. In general, deferment cutting did not result in significant changes in grade distributions in the first 2 to 5 years after treatment. Among large sawtimber (17.0 inches d.b.h. and larger), 11, 8, and 3 percent of white oak, black cherry, and northern red oak, respectively, exhibited grade reductions due to logging wounds or epicormic branches. Large sawtimber of other species did not exhibit grade reductions. Among small sawtimber (11.0 to 16.9 inches d.b.h.), grade reductions were more common compared to those for large sawtimber (Table 2). The development of epicormic branches was most prevalent on white oak. Suppressed and intermediate trees developed more epicormic branches and had more reductions in tree grade compared to those for codominant and dominant trees. In all of the 20 stands, logging wounds were found on 45 percent of residual trees, and 21 percent of trees had severe wounds larger than 100 in^2. However, the number of trees wounded and the severity of wounds were related to the months in which logging occurred (Fig. 2). Logging damage was greatest during the spring (March-June) and least during the dormant season (November-February). The data indicate that logging damage can be reduced by 50 percent if operations are conducted in the fall and early winter months.

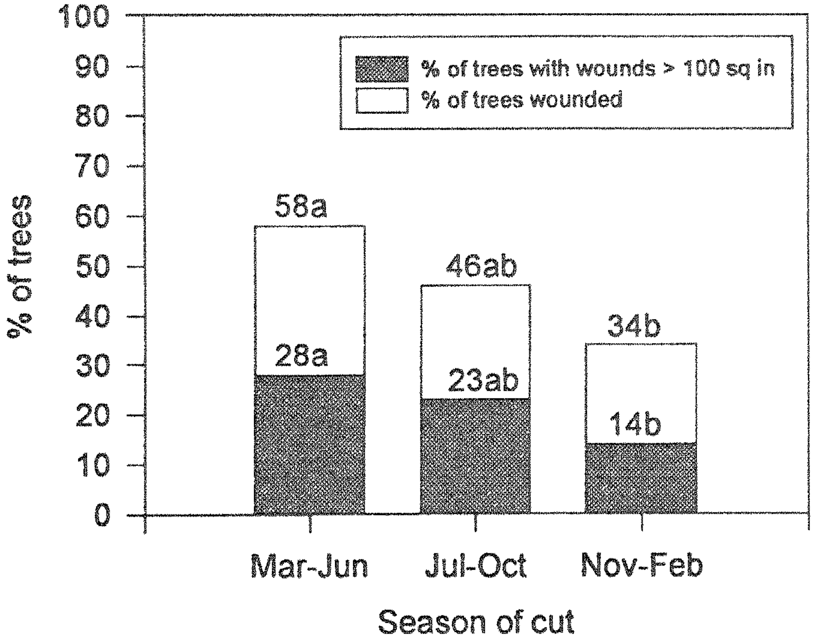

Figure 2.—Mean percent of residual trees with logging wounds. For bars of the same shade, means followed by the same letters are not significantly different at the 0.10 level based on analysis of variance followed by Tukey HSD.

The total number of noncommercial stems was relatively small, representing only 5, 12, and 28 percent of stems present in the beech-cherry-maple, mixed Appalachian hardwood, and mixed oak cover types, respectively. Noncommercial stems included striped maple, dogwood, pin cherry, sassafras, serviceberry, and American hornbeam. These stems are not expected to interfere with the growth and development of commercial species (Miller and Schuler 1995).

As these stands continue to develop, the trees in the new age class will form a height stratum distinct from the larger overstory trees left after logging. Stems present when data were collected will compete for crown position until the canopy of the new age class closes from 10 to 15 years after logging. At this point, most areas have adequate density and distribution of desirable reproduction. However, it is too soon to predict the eventual species composition. Trees that attain a codominant position at crown closure will determine the species composition of these stands for many years to come. Soon after crown closure, preferred crop trees can be given a crown release to assure their survival and competitive position within the stand.

Regeneration

Very small (< 1.0 ft tall) and small (≥ 1.0 ft tall and < 1.0-inch d.b.h.) reproduction was tallied within 1/1,000-acre circular plots, and large reproduction (1.0-inch d.b.h. and larger) was tallied within 1/100-acre circular plots. From 25 to 50 reproduction plots were located along systematic grids within each stand. For very small and small reproduction, stem counts and heights were recorded for each stem observed on a plot. For large reproduction, species, d.b.h., stem origin, quality, and crown class were recorded for each stem observed on a plot.

Stands were grouped by three forest cover types before regeneration results were summarized: beech-cherry-maple at the higher elevations in the Allegheny mountains, mixed Appalachian hardwoods in the coves of the Allegheny Mountains, and mixed oaks in the Ridge and Valley province east of the Allegheny Front. Most of the reproduction present on the survey plots was less than 1.0 ft tall (Table 3). In the beech-cherry-maple stands, reproduction was dominated by American beech, black cherry, and the birches, though many other species also were present. The mixed Appalachian hardwood stands contained the greatest diversity of species, though birches, maples, black cherry, and white ash were most abundant. Reproduction in the mixed-oak stands was dominated by red and sugar maple, birches, and northern red oak, though oak reproduction is difficult to sustain on high-quality growing sites. These results are consistent with other studies of two-age and even-age regeneration practices (Trimble 1973; Miller and Schuler 1995; Beck 1986).

Summary of Results

Results of this study were evaluated by land managers on the MNF and the following preliminary conclusions were drawn:

- Two-age silvicultural systems met the goals for timber, many wildlife species, and aesthetics.
- Residual basal area averaged 39 ft^2/acre; 82 percent of residual trees met timber objectives.
- Residual stands contained a mix of species, and 64 percent of residual trees were considered to be low-risk—expected to live more than 20 years after treatment.
- Only 8 percent of residual trees had died or blown over 2 to 4 years after treatment.
- Tree grades were not seriously reduced after treatment.
- The average size of logging wounds and the proportion of trees wounded was greatest for operations conducted from March through June, least from November through February.
- Regeneration was similar in composition and abundance to that observed after clearcutting.

DISCUSSION

Experience with two-age cutting since 1979 indicates that desirable reproduction can be established and will develop into an acceptable new crop for sustained production of

Table 3.—Summary of reproduction present 2-5 years after deferment cutting by forest cover type

Species	Beech-Cherry-Maple		Mixed Appalachian Hdwds		Mixed oaks	
	Very small[a]	Small[b]	Very small	Small	Very small	Small
	Number of stems/acre (% of plots stocked)					
Birches[c]	8,464(62)	1,989(31)	3,502(39)	2,324(24)	2,886(25)	137(9)
Maples	1,717(50)	641(16)	1,116(39)	516(19)	2,259(50)	556(14)
Red oaks	9(1)	3(1)	410(24)	203(11)	582(18)	100(7)
White oaks	0(0)	0(0)	80(8)	254(1)	103(6)	140(3)
Am. beech	2,268(55)	4,591(63)	83(4)	162(4)	20(1)	0(0)
Black cherry	6,357(68)	3,825(44)	820(25)	466(14)	40(2)	45(2)
Hemlock	68(3)	0(0)	0(0)	4(1)	0(0)	0(0)
White ash	38(3)	30(1)	829(22)	499(12)	30(30)	0(0)
Yellow-poplar	404(12)	70(4)	3,271(35)	62(3)	367(13)	18(2)
Am. basswood	0(0)	0(0)	4(1)	12(1)	0(0)	0(0)
Others	305(16)	68(5)	185(14)	396(17)	299(16)	520(20)
Total[d]	19,628	11,217	10,300	4,898	6,586	1,516

[a]Very small reproduction = all stems < 1.0 ft in height
[b]Small reproduction = stems ≥ 1.0 ft in height and < 1.0 inch dbh.
[c]Birches include sweet and yellow birch; maples include red and sugar maple; red oaks include northern red, scarlet, and black oak; white oaks include white and chestnut oak; others include blackgum, aspen, and cucumbertree.
[d]Data from 20 stands on the Monongahela National Forest where operational applications of deferment cutting were applied.

many forest benefits. The species composition includes a wide variety of shade-intolerant and shade-tolerant species that is similar to that observed after clearcutting. Cultural practices, such as crop-tree release, can be applied once the canopy of the new age class closes to favor the growth and development of the most desirable stems such as northern red oak.

Residual basal area in the early, experimental deferment cuts averaged 20 ft²/acre. In early operational two-age cuts on the MNF, the target residual basal area ranged from 20 to 40 ft²/acre, with actual residual basal area averaging 39 ft²/acre. More recently, new prescriptions call for 20 to 30 ft²/acre. Although residual trees in the experimental cuts were all potential high-quality sawtimber, residual trees in the operational cuts also included trees to help meet wildlife habitat objectives. In practice, residual trees may be selected by many criteria to help the forest manager achieve a wide range of objectives.

Where residual tree quality is a concern, trees in weaker crown positions or trees that show evidence of stress before treatment are most likely to lose quality. For most species, the strong codominants will not suffer grade reductions after deferment cutting. To reduce logging damage, operations should be conducted during the dormant season from November through January. To reduce windthrow, residual trees should not be selected above skid roads close to the cut bank where roots are disturbed.

To meet regeneration goals, residual basal area should range from 20 to 40 ft²/acre. However, if small sawtimber or poles are retained, maximum residual basal area will be reduced to allow for crown expansion as the overstory trees mature. It also is important to cut all stems 1.0 inch d.b.h. and larger other than the desired residual trees. Cutting these stems during logging eliminates low shade that interferes with regeneration and provides suitable growing conditions for the valuable shade-intolerant species.

Two-age regeneration harvests should be applied no more frequently than one-half the recommended economic sawtimber rotation for local conditions. In the central Appalachians, economic sawtimber rotations are 90, 80, and 70 years for northern red oak SI 60, 70, and 80, respectively. As a result, two-age harvests could be applied every 40 to 50 years to maintain a two-age stand structure, and some individual trees can be retained indefinitely to satisfy goals for longer rotations. A concern with relatively frequent harvests is that many large poles and small sawtimber need to be cut at short intervals in order to provide adequate light for regeneration of a new age class. At age 40, even-aged stands in the region contain 75 to 100 codominant stems per acre, with an average d.b.h. of only 10 inches. To maintain a two-age stand structure, 20 to 30 of the best codominant trees need to be retained to reach maturity, while the remaining trees will be cut. A disadvantage of short cutting intervals is that many cut trees will be removed at a time when their potential growth and value increase are at a maximum.

Due to differences in the timing and frequency of harvest cuts, economic returns from silvicultural alternatives are seldom directly comparable on the basis of returns from a single entry. However, estimates of harvesting costs and roundwood values indicate that implementing deferment cuts versus conventional clearcuts can reduce net cash flows from the initial regeneration cuts by $459 to $1,171/acre, or 18 to 26 percent, depending on site quality and roundwood price levels (Miller and Baumgras 1994; Baumgras and others 1995). These revenue reductions were estimated for fully stocked stands at age 80 years, and reflect the assumption that the residual trees were low-risk, dominants and codominants. These residual trees can make significant contributions to economic returns from future harvests, but diminish short-term returns to provide the desired non-timber amenities.

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LITERATURE CITED

Baumgras, J. E.; Miller, G. W.; Ledoux, C. B. 1995. **Economics of hardwood silviculture using skyline and conventional logging.** In: Lowery, G.; Meyer, D. eds. Advances in hardwood utilization: following profitability from the woods through rough dimension. Proceedings of the 23rd Annual Hardwood Symposium; 1995 May 17-20; Cashiers, NC. Memphis, TN: National Hardwood Lumber Association: 5-17.

Beck, D. E. 1986. **Management options for southern Appalachian hardwoods: the two-aged stand.** In: Phillips, D. R., comp. Proceedings of the 4th Biennial Southern Silvicultural Research Conference; 1986 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 451-454.

Bennett, A. L.; Armstrong, M. M. 1981. **Insurance silviculture in the black cherry-maple type.** Journal of Forestry. 79:146-149, 154.

DeGraaf, R. M.; Scott, V. E.; Hamre, R. H.; Ernst, L.; Anderson, S. H. 1991. **Forest and rangeland birds of the United States**: Agric.Handb. 688. Washington, DC: U.S. Department of Agriculture. 625 p.

Hanks, L. F. 1976. **Hardwood tree grades for factory lumber.** Res. Pap. NE-333. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 81 p.

Johnson, J. E.; Miller, G. W.; Baumgras, J. E.; West, C. D. **An assessment of residual stand quality and regeneration following two-age cutting in central Appalachian hardwoods.** Northern Journal of Applied Forestry. (in review).

Kostler, J. N. 1956. **Silviculture.** Anderson, M. L., trans. Aylesbury and London: Oliver and Boyd Ltd. 416 p.

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 Research Council; 1994 May 12-15; 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. 1995. 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: Forest health through silviculture. Proceedings of the 1995 National Silviculture Workshop. Eskew, L. G., comp. Gen. Tech. Rep. RM-GTR-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Range and Forest Experiment Station: 175-182.

Miller, G. W. 1996. **Epicormic branching on central Appalachian hardwoods 10 years after deferment cutting.** Res. Pap. NE-702. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 9 p.

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

Smith, H. C. 1988. **Possible alternatives to clearcutting and selection harvesting practices.** In: Smith, H. C.; Perkey, A. W.; Kidd, W. E. Eds. Proceedings: Guidelines for regenerating Appalachian hardwood stands; 1988 May 24-26; Morgantown, WV. SAF Publ. 88-03. Morgantown, WV: West Virginia University Books: 276-289.

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

Smith, H. C.; Miller, G. W. 1991. **Deferment cutting in Appalachian hardwoods: the what, whys, and hows.** In: Johnson, J. E., ed. Uneven-aged silviculture of Upland hardwood stands workshop; 1991 February 25-27; Blacksburg, VA: Virginia Polytechnic Institute and State University: 20-25.

Smith, H. C.; Miller, G. W.; Schuler, T. M. 1994. **Closure of logging wounds after 10 years.** Res. Pap. NE-692. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6p.

Trimble, G. R., Jr. 1973. **The regeneration of central Appalachian hardwoods with emphasis on the effects of site quality and harvesting practice.** Res. Pap. NE-282. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 14 p.

Trimble, G. R.,Jr ; Seegrist, D. W. 1973. **Epicormic branching on hardwood trees bordering forest openings.** Res. Pap. NE-261. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Troup, R. S. 1966. **Silvicultural systems.** Oxford, U.K.: Oxford Clarendon Press. 216 p.

Wood, P. B.; Nichols, J. V. 1995. **Effects of two-age timber management on songbird density and reproductive success.** Progress report to Monongahela National Forest, Elkins, WV. 90 p.

Use of Molecular Genetic Markers in Forest Management

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Abstract.—When managing forests for biodiversity or sustainability, attention must be given to how silvicultural practices affect genetic diversity. A new generation of DNA-based markers affords a greater detail of genetic analysis than previously possible. These new markers, SSRs or microsatellites, have been used to demonstrate genetic diversity and infer evolutionary history of red pine, something that has not been possible with other markers. SSR markers developed by the Forest Service Research Biotechnology Unit are also being used to monitor how methods of sustainable timber management affect genetic diversity and breeding patterns within white pine stands on the Menominee Indian reservation.

INTRODUCTION

Often the goal of silvicultural prescriptions is nothing less than the management, or manipulation, of ecosystems. The importance of considering the effects on the genetic diversity of forest species when making such management decisions has been expertly reviewed (Conkle 1992; DeWald and Mahalovich 1997; El-Kassaby 1992; Ledig 1988; Li et al. 1992; Millar and Westfall 1992; Namkoong 1991; Savolainen and Kärkkäinen 1992; Yang and Yeh 1992). Maintenance of genetic diversity is also part of the biodiversity standards that have recently been proposed for forest plantations (Spellerberg and Sawyer 1996). The most efficient way to monitor natural or managed changes in genetic diversity is with protein or DNA-based (molecular) markers that are neutral with respect to natural selection. (Definitions of various terms, such as 'genetic marker', are provided in the final section of this paper.) A recently discovered class of DNA-based markers promises efficient and thorough assessment of alterations in genetic diversity for select forest species. In this presentation, progress in the application of these markers to address issues in forest management will be described, as will the approaches being used to communicate the role of forest research to those involved or interested in resource management.

SSR MARKERS IN FOREST GENETICS

Microsatellites, or simple sequence DNA repeats (SSRs), came to prominence in the field of genetics only during this past decade, due in large part to their medical applications in human disease research and DNA fingerprinting. But SSRs are highly abundant and variable in most organisms, not just humans, and thus serve as a universal source of highly informative genetic markers. In pine genomes, for example, there are several hundred thousand SSR sites (Echt and May-Marquardt 1997). It is expensive and time-consuming to develop the molecular genetic information needed to use SSRs as genetic markers, but several forest research laboratories are involved in the process for pines (Echt et al. 1996; Fisher et al. 1996; Kostia et al. 1995; Smith and Devey 1994), spruces (Pfeiffer et al. 1997; VandeVen and McNicole 1996), and oaks (Dow et al. 1995). Preliminary results from research in the author's laboratory indicate that SSR markers developed in one species, can be used in closely related species, thus leveraging marker development investments. The major advantages of using SSR markers over other types of markers, such as isozymes, RAPDs, or RFLPs, is that they generally have a large number of alleles at a locus, allele identification is unambiguous, heterozygosity is easily determined, they can be used among all members of a species, and they are quickly and efficiently analyzed from very small amounts of plant tissue. Given the increased resolution of genetic discrimination possible with SSR markers, they can be considered the "Hubble telescope" of genetics research.

In addition to their presence in the nuclear genome, SSRs are also found in the DNA of chloroplasts, and can serve as highly informative organellar markers. A number of chloroplast SSR (cpSSR) markers are available for use in conifers (Cato and Richardson 1996; Powell et al. 1995; Vendramin et al. 1996). Since in many species chloroplast DNA is uniparentally inherited (in conifers it is transmitted through pollen), cpSSR markers can provide information about evolutionary lines of decent among populations.

Fundamental information about the SSR markers and their uses can be found on-line through the Dendrome Forest Genetics World Wide Web server. This information is provided and updated by the author as a service to the forest research community. The URL address for white pine SSR markers is: http://s27w007.pswfs.gov/Data/echt_ssr_primers.html, that for hard pine SSR markers is: http://s27w007.pswfs.gov/Data/chloroplast.html, and information about cpSSR markers can be found at: http://s27w007.pswfs.gov/Data/ hardssr.html.

RED PINE POPULATION DIVERSITY AND EVOLUTIONARY HISTORY

Background

Genetic diversity of red pine, *Pinus resinosa* Ait., is extremely low, perhaps dangerously low, throughout its range. Red pine is an important timber species in the northcentral and northeastern United States, as well as in Canada. In Minnesota, Wisconsin and Michigan alone there are almost 1.8 million acres of red pine, valued at over $3 billion, and this area is only a fraction of the North American range of the species (Leatherberry et al. 1996; Miles et al. 1995; Spencer et al. 1988). Knowledge of the amount and distribution of genetic diversity of red pine is critical to management of this important natural resource.

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Table 1.—Locations of red pine populations

code	provenance	seedlot#	lat./long.	Elevation.(m)
A	Nova Scotia, Beaver Lake	7010280	44.14/65.20	140
B	Ontario, Eldridge Twnshp	7030250	47.00/79.30	310
D	Ontario, Sioux Lookout	6830060	50.04/91.57	370
E	Quebec, Norway Bay	7023040	45.32/76.26	80
F	Michigan, Delta Co.	5780350	46.00/87.00	NA
G	New Brunswick, Tracy	7010310	45.43/66.42	60
H	Ontario, Macdiarmid	7030260	49.18/88.05	370

The high level of homozygosity observed in red pine is thought to have resulted from one, or a series of, population bottlenecks. The most recent drastic decrease in population size (a population bottleneck) to have affected the species as a whole is thought to have occurred during the last Pleistocene glaciation 20,000 years ago, when red pine was restricted to refugial populations in the Appalachian highlands of present day West Virginia (Fowler and Morris 1977). The disjunct, dispersed populations found throughout the species' current range promote inbreeding which further increases homozygosity (Fowler and Lester 1970; Mosseler 1992).

Morphological and phenological uniformity are characteristic of the species (Fowler 1964; Fowler and Lester 1970). While some variation among provenances has been reported, it is much less than what is observed for other northern pines and the heritability of the variation has not been established (Fowler 1965; Wright et al. 1972; Ager et al. 1983). A narrow genetic base puts red pine at risk of extinction from exotic pests, disease epidemics, or rapid climate change, and can be further eroded by mismanagement. Thus there is a need to efficiently identify sources of genetic diversity so that divergent germplasm may be preserved, both in the forests and in seed orchards where it could be utilized in tree improvement programs.

Results

Since no other marker system had previously revealed genetic variation in red pine, cpSSR markers were used to survey 159 individuals among seven populations distributed across the natural range of the species (Table 1). As expected, the higher variability of cpSSRs allowed population differences to become evident. Measures of within population diversity (Table 2) indicated that a population in Tracy, New Brunswick harbored more chloroplast haplotype variability than any other population, and that no two populations were genetically identical. Examination of the genetic relationships among populations, and of the distribution of haplotype differences among individuals within populations, indicated that red pine, as a species, recovered rapidly from a population bottleneck. These results lend strong support to the previously formulated population bottleneck theory, but what was not so evident from previous observations, and what the cpSSR data clearly indicated, was that individual populations of red pine arose at different evolutionary times and possibly from different lines of decent.

Table 2.—Measures of cpSSR haplotype variation within populations

Population	n_e	f_a	H_e
A	1.430	0.833	0.314
B	2.153	0.667	0.559
D	2.998	0.545	0.698
E	2.924	0.429	0.691
F	1.754	0.750	0.449
G	8.397	0.217	0.920
H	1.497	0.810	0.348

n_e, Effective number of haplotypes in each population
f_a, Frequency of the most common haplotype
H_e, measure of unbiased genetic diversity

Red pine is thus not a genetically homogeneous specie, at least where the evolutionary origins of individual populations are concerned. More extensive cpSSR surveys should identify populations throughout the range of red pine that have the highest levels of diversity, and thus help set guidelines for genetic resource conservation programs of red pine. Genotyping of populations with nuclear SSR markers will be needed to assess the degree of population genetic differentiation of genes in the nuclear genome. Since the chloroplast microsatellite approach revealed population genetic differences in a species characterized by no detectable allozyme variation, it should also be considered for studying population structures of other forest species that have low genetic diversity, such as Torrey pine, *Pinus torreyana* Parry ex Carr, (Ledig and Conkle 1982) or western red cedar, *Thuja plicata* Donn ex E. Don., (Copes 1981).

GENETIC DIVERSITY OF NATURAL AND MANAGED WHITE PINE STANDS

Background

To achieve sustainable and ecologically sound white pine management there is a need to know whether certain practices maintain native levels of genetic diversity, or whether they narrow that diversity and foster greater inbreeding within managed stands. When artificial reforestation is used, it is also of benefit to know whether there are genetic subdivisions, or subpopulations, of trees within a management area. Such knowledge is useful for establishing seed transfer guidelines.

A previous study of eastern white pine populations in Quebec found that there are high levels of isozyme diversity, high gene flow among populations and no measurable population genetic differentiation across the range (Beaulieu and Simon 1994). In an isozyme study of eastern white pine mating systems, essentially no excess of inbreeding was found in two natural Quebec populations that differed in their stand densities of from 800 to 100 trees/acre (Beaulieu and Simon 1995).

Table 3.—Populations samples from white pine stands and site characteristics

stand	overstory (density)	cone seeds collected	regen., natural	regen., artificial
SP	~240 yr (2/ac)	-	-	-
PP	~160 yr (40/ac)	-	-	-
MC	~160 yr (3/ac)	√	40 yr	-
C1	~160 yr (40/ac)	√	3 yr	-
OL	~160 yr (20/ac)	-	9 yr	-
EL	none	-	-	8 yr

Ongoing research in the Biotechnology Unit at Rhinelander involves assessing the genetic diversity of white pine, *Pinus strobus* L. A study is in progress with white pines managed by Menominee Tribal Enterprises in Menominee County, Wisconsin, to determine how certain silvicultural practices affect genetic diversity across the 234,000-acre reservation. Instead of isozymes, SSR markers developed by Echt et al.(1996) and cpSSR markers developed by Vendramin et al. (1996) are being used.

Here are some of the questions that the Menominee foresters hope to have answered by this research: Is gene diversity distributed equally among populations across the county? Does genetic variation and gene flow change under different management strategies? How does overstory density affect genetic diversity and degree of inbreeding among the regenerated progeny? Is off-site seed genetically equivalent to local seed sources?

Besides assisting forest managers in long-term planning of tribal resources, the Menominee study will supply additional basic information on white pine diversity in the North Central Lake States region. It is expected that regional white pine information eventually will be combined with data from eastern U.S. populations, and from similar studies occurring in Canada, to construct a continental database for white pine population genetic diversity and structure. Such information could be used in formulating area-wide management and planning decisions.

The Menominee Study Plan

Six sites, involving nine populations of individuals, were selected for study by Dan Pubanz, a Menominee Tribal Enterprises forester (Figure 1). Five of the site are actively managed, and the sixth (School Pines - SP) is representative of a remnant, natural population that has not been thinned. Of the five managed stands, one (East Line Plantation - EL) was artificially regenerated from off-reservation seedlings, three sites (Potato Patch - PP, Camp One - C1, Oconto Line - OL) are under shelterwood management, and one (Minnow Creek - MC) is a pine release management site. Age classes of the overstory and regenerated populations are provided in Table 3. Fifty individuals from both the overstory and regenerated generations at each site will be sampled. From the same 50 mature trees at the MC and C1 sites, which differ ten-fold in their overstory densities, seed will also be collected to estimate pollen flow and current levels of inbreeding and outcrossing that are occurring within the sparse overstory. GPS coordinates were obtained for all the trees sampled, so spatial genetic analyses will be possible to look for patterns in genetic differences within and among populations. Each tree, seedling, and seed will be genotyped for 10 nuclear SSR loci and haplotyped for 10 cpSSR loci. Statistical analyses will be performed to quantify genetic diversity and levels of inbreeding, both within and among individual populations. The nuclear marker data from trees and seedlings will provide information on how certain silvicultural practices affect levels of heterozygosity, inbreeding and gene diversity, while the nuclear SSR marker and cpSSR marker data from seeds and seedlings will provide information on patterns of pollen flow. Data from cpSSR haplotypes of trees will also be used to look at historic patterns of dispersal of white pine. Once the Menominee study is complete, the tribal foresters hope to use the genetic diversity information as part of the biodiversity component of their timber recertification process with Scientific Certification Systems.

Results

To date, DNA has been isolated from 450 trees and genotyping has been done for two SSR loci. Forty seeds will be collected from each of 100 trees in the fall of 1997. Although no firm conclusions can be drawn from just two loci, the preliminary results demonstrate the type of information that genetic surveying with SSR markers can provide silviculturalists.

The two SSR loci each had 14 alleles, which resulted in total gene diversity being high across the reservation ($H_t = 0.73$). There was very little genetic differentiation among stands ($G_{st} = 2\%$), meaning that diversity across the reservation was not highly structured. Even so, there were small, but significant genetic differences separating each stand such that genetic distance trees (phenograms) could be constructed to represent the genetic relationships of populations to each other. Naturally regenerated progenies, as expected, were genetically most similar to their parents, with the interesting exception of the Minnow Creek pine release management site. At that site the regenerated saplings had a distinctly different genetic makeup from the overstory trees that were left after thinning. The reason for this difference is not known and additional study is needed. Off-site seedlings (EL) were a bit less diverse than, but were genetically quite similar to, on-site seedlings.

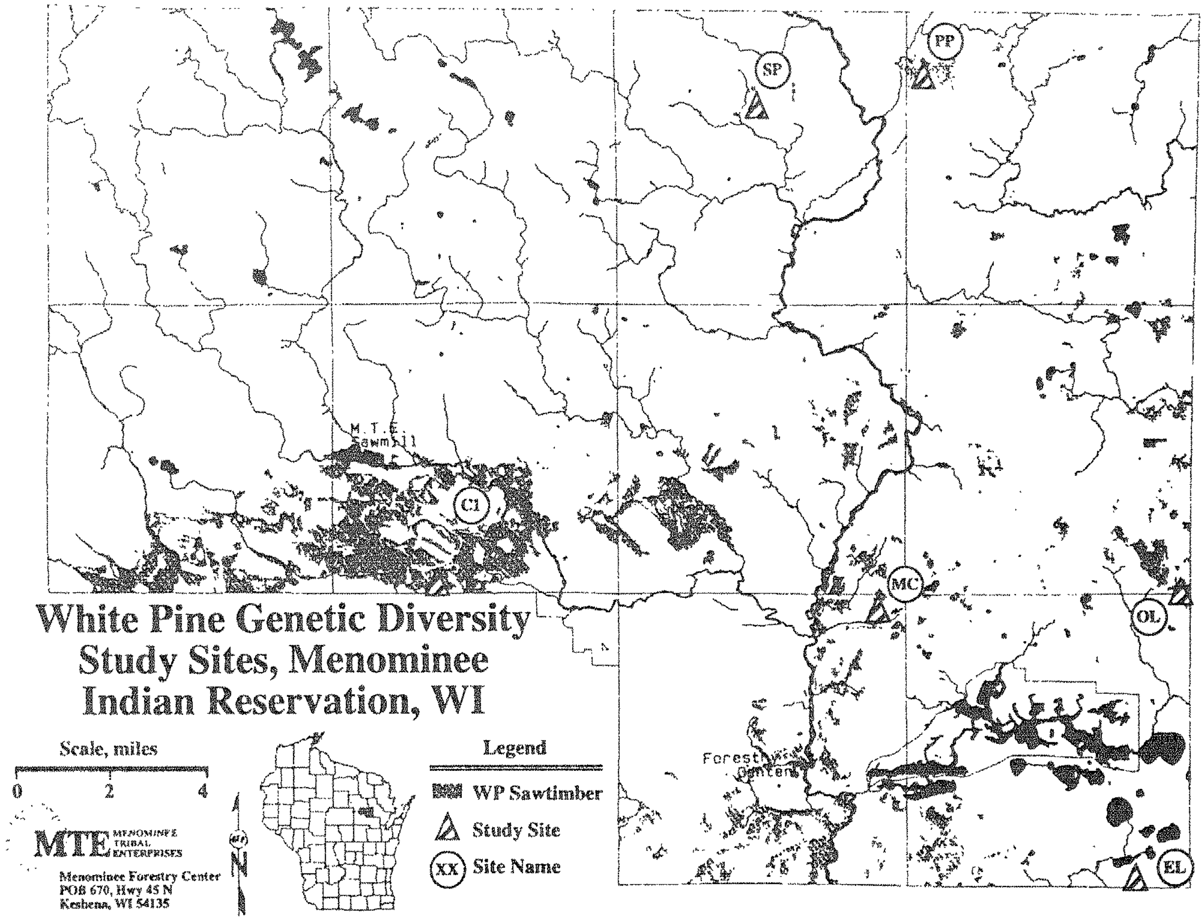

Figure 1.—Site map of study areas, and sawtimber white pine range, in Menominee County, Wisconsin.

Again based on data from just two loci, there was a general, but slight, deficiency of heterozygotes across the reservation (F_{it} = 0.20), suggesting that there has been more mating among relatives (inbreeding) than would have been expected in purely randomly mating populations. Inbreeding was always more pronounced among the parental generations. That is, there appeared to have been more inbreeding occuring 160 to 240 years ago than is occuring now in the managed stands. Since the regenerated seedling populations were less inbreed (more heterozygous) than their parents, Menominee silvicultural practices appear to be preserving, or even increasing, genetic diversity within managed white pine stands.

These preliminary results stand in contrast to a study of white pines in Ontario that used 18 isozyme loci, in which there were an average of only 2 alleles per locus, and gene diversity was about one sixth of that in the Menominee forests (Beaulieu and Simon 1994). While that study found a similar distribution of gene diversity within and among populations, the Ontario populations did not demonstrate an appreciable degree of inbreeding. Whether these differences result from differences between the information provided by isozyme and SSR markers, or from true biological differences between the populations, remains to be seen.

DEFINITIONS OF TERMS

Genome

The total genetic component of an organelle, individual or species. If only the word 'genome' is used, then it refers to all the DNA present in the nucleus. 'Chloroplast genome' and 'mitochondrial genome' refer to the total DNA present in those particular organelles.

Genotype, Haplotype and Phenotype

A genotype is an abstract, symbolic expression of the genetic factors (genes or loci) responsible for a phenotype. Genotyping is the process of determining the specific alleles that are present in an individual or population. While genotypes are expressions of the genetic constitution of diploids, where both sets of chromosomes are considered, haplotypes are expressions of the genetic constitution of haploids, where only one set of chromosomes (either the mother's or the father's) are considered. Scoring alleles in leaves or roots will give you genotypes, while scoring alleles in conifer megagametophyte or in chloroplast DNA, will give you haplotypes. A phenotype is an observable, heritable character, and is the physical aspect of the underlying genetic factors. Once the genetic factors are identified, every phenotype can be symbolically represented by a genotype. A band on a gel, a cellular metabolite, or the angle of a branch, can all be considered phenotypes, as long as they are heritable characters.

Markers, Alleles and Loci

A marker is a quantifiable character that distinguishes, or marks, underlying genetic differences between individuals. It is often encountered as a particular enzyme or DNA fragment having a defined position on an electrophoretic gel. Any given 'band on a gel' does not gain marker status, however, unless two or more forms (alleles) of it exist at a single chromosomal location (locus). The plural of locus is loci. At their most fundamental level alleles are simply the DNA sequence variants found at a locus.

Oligonucleotide, Primer

DNA is a polymer of nucleotides, or a polynucleotide. A short piece of DNA is an oligonucleotide. An oligonucleotides usually refers to a piece of single stranded DNA, although it can be double-stranded, and is generally 10-100 nucleotides in length. An oligonucleotide primer, or simply, primer, is a single stranded oligonucleotide that anneals to a complementary sequence on single stranded DNA (the template DNA) and directs, or primes, the synthetic action of a class of enzymes called DNA polymerases. When two primers are used to direct the amplification of a locus by PCR they are called PCR primer pairs.

PCR (Polymerase Chain Reaction)

A Nobel Prize-winning technique for replicating and amplifying (cloning) specific DNA fragments in a test tube. The key component of PCR is a heat stable DNA polymerase called Taq polymerase, after the hot springs bacteria *Thermus aquaticus* from which it is purified. The extent of DNA that is amplified is determined by the two PCR primers which anneal to opposite DNA strands at the ends of the target DNA segment. In theory, millions of copies of target DNA can be amplified from a single DNA template molecule (a single cell!), but in common practice the starting point is several hundred copies of the DNA template. Thus, from just several hundred cells, a specific locus can be genotyped with a PCR-based marker. In pines, a typical PCR marker of 200 base pairs in length represents 1/100 millionth of the total length of DNA present in the nucleus. It is this discriminatory power of PCR that makes it the most powerful tool available for genetic analysis.

SSR (simple sequence repeat), or microsatellite DNA

A class of tandemly repeated DNA sequences that are highly variable, and which are used extensively as genetic markers. Examples of SSRs are $(AG)_{10}$ - the sequence of nucleotides deoxyAdenosine and deoxyGuanosine repeated 10 times - or $(ACT)_8$ - the sequence deoxyAdenosine, deoxyCytidine and deoxyThymidine repeated 8 times. SSR repeats are found in abundance throughout the nuclear DNA of most organisms. Each repeat that serves as a SSR marker is surrounded by unique, non-repetitive DNA. It is this unique DNA that allows identification of individual SSR loci along the chromosomes, while the embedded repeat DNA provides the informative variation. SSR loci can be analyzed by PCR once the DNA sequence of the repeat and its surrounding DNA is determined. These DNA sequences allow the unique PCR primer pairs to be designed and chemically synthesized.

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LITERATURE CITED

Ager, A., Guries, R., Lee, C. H. 1983. **Genetic gains from red pine seedling seed orchards.** Proceedings of the 28th Northeastern Forest Tree Improvement Conference, pp175-194. Institute of Natural and Environmental Resources, Univ. of New Hampshire, Durham, NH. July 7-9.

Beaulieu, J., and Simon, J. P. 1994. **Genetic structure and variability in *Pinus strobus* in Quebec.** Canadian Journal of Forest Research, 24:1726-1733.

Beaulieu, J., and Simon, J. P. 1995. **Mating system in natural populations of eastern white pine in Quebec.** Canadian Journal of Forest Research, 25:1697-1703.

Cato, S. A., and Richardson, T. E. 1996. **Inter- and intraspecific polymorphism at chloroplast SSR loci and the inheritance of plastids in *Pinus radiata*, D. Don.** Theoretical and Applied Genetics, 93:587-592.

Copes, D. L. 1981. **Isoenzyme uniformity in western red cedar seedlings from Oregon and Washington.** Canadian Journal of Forest Research, 11:451-453.

DeWald, L. E., and Mahalovich, M. F. 1997. **The role of forest genetics in managing ecosystems.** The Forestry Journal, 95:12-16.

Dow, B. D., Ashley, M. V., and Howe, H. F. 1995. **Characterization of highly variable (GA/CT)n microsatellites in the bur oak, *Quercus macrocarpa*.** Theoretical and Applied Genetics, 91:137-141.

Echt, C. S., and May-Marquardt, P. 1997. **Survey of microsatellite DNA in pine.** Genome, 40:9-17.

Echt, C. S., May-Marquardt, P., Hseih, M., and Zahorchak, R. 1996. **Characterization of microsatellite markers in eastern white pine.** Genome, 39:1102-1108.

El-Kassaby, Y. A. 1992. **Domestication and genetic diversity - should we be concerned?** Forestry Chronicle, 68: 687-700.

Fowler, D. P. 1964. **Effects of inbreeding in red pine, *Pinus resinosa* Ait. I. Natural variation.** Silvae Genetica, 13, 170-177.

Fowler, D. P. 1965. **Effects of inbreeding in red pine, *Pinus resinosa* Ait. IV. Comparison with other northeastern *Pinus* species.** Silvae Genetica, 14, 76-81.

Fowler, D. P. And Lester, D. T. 1970. **The genetics of red pine.** USDA Forest Service Research Paper W-8, pp 13.

Fowler, D. P. and Morris, R. W. 1977. **Genetic diversity in red pine: evidence for low genic heterozygosity.** Canadian Journal of Forest Research, 7:343-347.

Fisher, P. J., Gardner, R. C., and Richardson, T. E. 1996. **Single locus microsatellites isolated using 5' anchored PCR.** Nucleic Acids Research, 24:4369-4372.

Kostia, S., Varvio, S., Vakkari, P., and Pulkkinen, P. 1995. **Microsatellite sequences in a conifer, *Pinus sylvestris.*** Genome, 38:1244-1248.

Leatherberry, E. C. and Spencer, J. S., Jr. 1996. **Michigan Forest Statistics, 1993.** USDA Forest Service. Resource Bulletin NC-170.

Ledig, F. T. 1988. **The conservation of diversity in forest trees: Why and how should genes be conserved?** BioScience, 38:471-479.

Ledig, F. T. and Conckle, M. T. 1983. **Gene diversity and genetic structure in a narrow endemic, Torrey pine (*Pinus torreyana* Parry ex. Carr.).** Evolution, 37:79-85.

Li, P., MacKay, J., and Bousquet, J. 1992. **Genetic diversity in Canadian hardwoods: implications for conservation.** Forestry Chronicle, 68: 709-719.

Miles, P. C. Chen, C. M., and Leatherberry, E. C. 1995. **Minnesota Forest Statistics, 1990, Revised.** USDA Forest Service, Resource Bulletin NC-158.

Millar, C. I., and Westfall, R. D. 1992. **Allozyme markers in forest genetic conservation.** New Forests, 6:347-371.

Mosseler, A. 1992. **Life history and genetic diversity in red pine: implications for gene conservation in forestry.** The Forestry Chronicle, 68:701-708.

Namkoong, G. 1991. **Biodiversity - issues in genetics, forestry and ethics.** The Forestry Chronicle, 68:438-443.

Savolainen, O., and Kärkkäinen, K. 1992. **Effect of forest management on gene pools.** New Forests, 6:329-345.

Smith, D. N., and Devey, M. E. 1994. **Occurrence and inheritance of microsatellites in *Pinus radiata.*** Genome, 37:977-983.

Spellerberg, I. F., and Sawyer, J. W. D. 1996. **Standards for biodiversity:A proposal based on biodiversity standards for forest plantations.** Biodiversity and Conservation, 5:447-459.

Spencer, J. S., Jr., Smith, W. B., Hahn, J. T., and Raile, G. K. 1988. **Wisconsin's Fourth Forest Inventory 1983.** USDA Forest Service, Resource Bulletin NC-107.

Pfeiffer, A., Olivieri, A., and Morgante, M. 1997. **Identification and characterization of microsatellites in Norway spruce (*Picea abies* K.) Genome, 40**: in press.

Powell, W., Morgante, M., McDevitt, R., Vendramin, G., and Rafalski, J.A. 1995. **Polymorphic simple sequence repeat regions in chloroplast genomes: Applications to the population genetics of pines.** Proc. Natl. Acad. Sci. USA, 92:7759-7763.

Wright, J. W., Read, R. A., Lester, D. T., Merritt, C., and Mohn, C. 1972. **Geographic variation in red pine: 11-year data from the North Central states.** Silvae Genetica, 21:205-222.

VandeVen, W. G. and McNicole, R. J. 1996. **Microsatellites as DNA markers in Sitka spruce.** Theoretical and Applied Genetics, 93:613-617.

Vendramin, G. G., Lelli, L., Rossi, P., and Morgante, M. 1996. **A set of primers for the amplification of 20 chloroplast microsatellites in *Pinaceae.*** Molecular Ecology, 5:595-598.

Yang, R., and Yeh, F.C. 1992. **Genetic consequences of *in situ* and *ex situ* conservation of forest trees.** Forestry Chronicle, 68:720-729.

North American Long-Term Soil Productivity Research Program

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Abstract.—The National Long-term Soil Productivity research program was chartered to address National Forest Management Act concerns over possible losses in soil productivity on National Forest lands. The program supports validation of soil quality monitoring standards and process-level productivity research. Summarized results are supplied to Forests as collected. National Forest managers use them in developing forest plans and modifying management practices. Results are treated as the best available evidence and are used within the adaptive management process.

INTRODUCTION

Origins of the Long Term Soil Productivity (LTSP) program can be traced from informal discussions in 1986 between National Forest System (NFS) managers and Forest Service Research (FSR) scientists. NFS managers needed valid soil quality monitoring standards as a consequence of the National Forest Management Act of 1976 (NFMA), and sought help from Forest Service Research. Researchers needed a more fundamental understanding of site productivity and the processes controlling it to develop and evaluate alternative silvicultural systems. Open and active communication between researchers and managers led to a major review paper on the world' s experience concerning declines in fundamental productivity (Powers and others 1990) and a template for what was to become the LTSP program. Further technical discussion between Forest Service scientists, international scientists, and researchers from several U. S. universities and forest industry resulted in a generic study plan which was drafted and circulated for national review. In 1989, following national review, the LTSP plan became an official Forest Service cooperative program with the signing of the national study plan by the Deputy Chiefs for National Forest Systems and Research[2].

DESIGN AND IMPLEMENTATION

Background

Soil was selected as an indicator of site productivity potential because it is a fundamental resource that controls the quantity and quality of such renewable forest resources as timber, wildlife habitat, forage, and water yield, and because it is a non-renewable resource directly affected by forest management practices. The USDA Office of General Council interprets land productivity to mean the inherent capacity or potential of a soil to produce vegetation[2]. The LTSP program centers on two concepts:

1. the soil is the key site factor controlling productivity that is affected by management, and
2. the fundamental measure of productivity is the site's carrying capacity for plant growth.

Research has shown that productivity declines on non-wetland sites are related principally to site organic matter losses and soil porosity reductions (Powers and others 1990). Although concepts are well established, there is little specific understanding of how site organic matter and soil porosity are linked to control fundamental processes governing productivity or what threshold levels of organic matter and soil porosity are needed to maintain site productivity.

The national study has three main objectives:

1. Validating regional soil quality monitoring standards against soil productivity potential;
2. Determining the productive potential of the land for vegetative growth; and
3. Understanding how soil porosity and site organic matter interact to regulate long-term site productivity.

These objectives are best addressed by a designed experiment with treatments effecting large, systematic changes in fundamental soil properties. A controlled experiment is preferable to quantifying operational practices which are difficult to control, generally confound several variables, vary from region to region, and are likely to become obsolete.

Experimental Design and Treatments

Each installation of the study (Figure 1) consists of a core set of nine plots which represent all possible combinations of three levels of compaction (none, moderate, and severe) and three levels of organic matter removal (bole only, bole + crown, and total above-ground organic matter). The 1-acre plots are regenerated with the species or species group appropriate to each region. Each plot is split into two equal parts with one half receiving total competition control, focusing site resources only on the subject trees. The other half receives no competition control and the plant community is allowed to develop. Along with the core experiment, plots of ameliorative treatments and best

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[2]USDA Forest Service. 1989. Evaluating timber management impacts on long-term soil productivity: a Research and National Forest System cooperative study. Study Plan. 32 p.

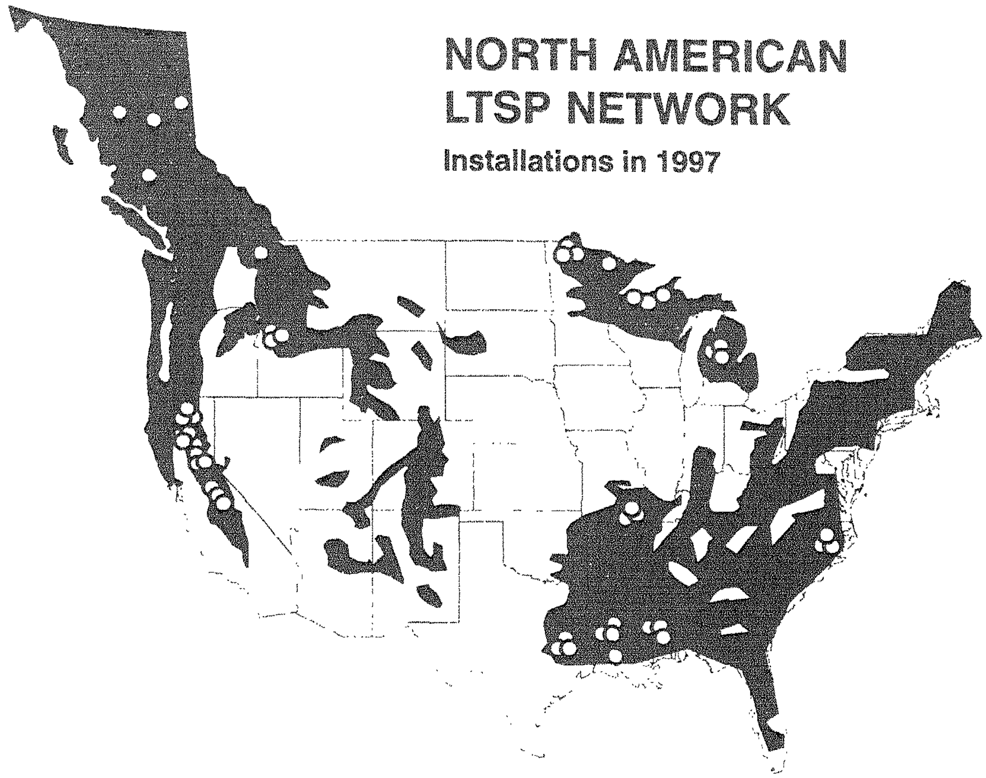

Figure 1.—Locations of current LTSP installations in North America.

management practices are added at many LTSP sites to see how soil productivity can be restored or improved. The standardized experimental design is shown in Figure 2. Most sites are on National Forests, but in Missouri the plots are located on state lands as is one installation in California. Researchers in the British Columbia Ministry of Forests, Canada, adopted the LTSP design and have installations at four locations with more planned. Locations of the current LTSP study installations are shown in Figure 1 and Table 1 summarizes the forests and species. Our discussion centers on the U.S. Forest Service phase of LTSP.

Candidate sites are arrayed along a gradient in soil properties believed to be directly linked to potential productivity, recognizing that the importance of any suite of properties varies by region. Study sites are selected from the candidates to cover the range of soil-site conditions found within a timber type.

Implementation

The design, installation, development of research of soil processes, maintenance and protection of this network was accomplished by direct communication between NFS managers

Table 1—Location and species of current LTSP study installations.

Region/ Station	National Forest/ Experimental Forest	Number of Installations	Species
1/RM	Priest River	1	Hemlock
4/RM	Boise	3	Mixed Conifer
5/PSW	Blodgett (Univ. CA)	1	Mixed Conifer
5/PSW	Eldorado	1	Mixed Conifer
5/PSW	Lassen/Black's Mountain	3	Mixed Conifer
5/PSW	Plumas	2	Mixed Conifer
5/PSW	Sierra	3	Mixed Conifer
5/PSW	Tahoe	2	Mixed Conifer
8/SRS	Davy Crocket	3	Loblolly Pine
8/SRS	DeSoto	3	Loblolly Pine
8/SRS	Croatan	3	Loblolly Pine
8/SRS	Kisatchie	1	Loblolly Pine
8/SRS	Kisatchie	3	Loblolly Pine
9/NC	Chippewa/Marcell	1	Aspen
9/NC	Chippewa	3	Aspen
9/NC	Huron	3	Aspen
9/NC	Ottawa	3	Aspen
9/NC	MO Dept. of Conservation	3	Oak-Hickory
BC[a]	Prince George	3	Lodgepole Pine/White Spruce
BC	Prince George	1	Aspen

[a] Plots in Prince George Province, Canada were installed following the specifications of the USDA Forest Service study and are considered part of the LTSP network for data analysis.

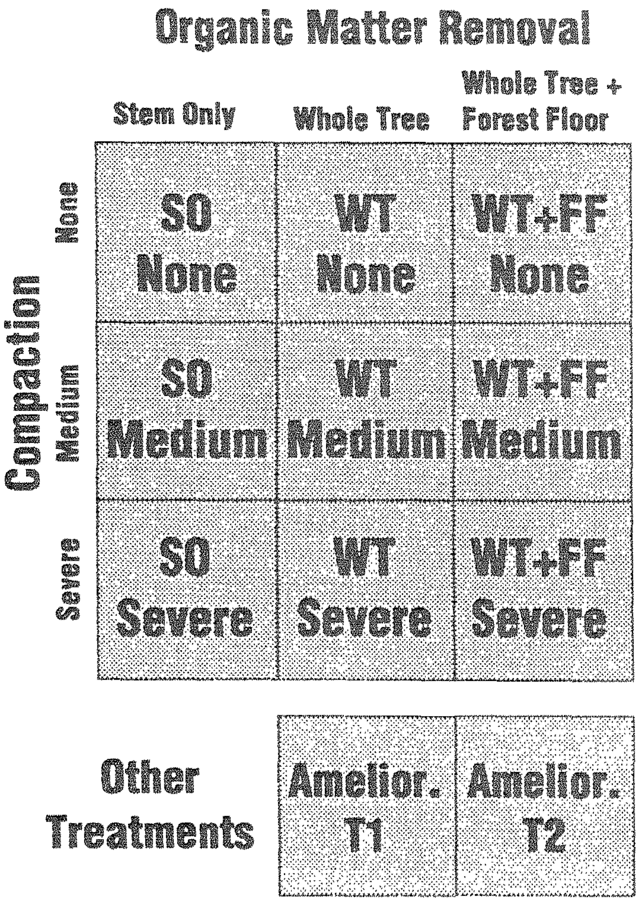

Figure 2.—Standardized experimental design for LTSP treatments. Each whole-plot treatment has competing vegetation controlled on one of the plot and the other half receives no competition control. Treatments to enhance productivity (amelioration) may be added.

and FSR scientists. Through times of tight budgets and shrinking resources, LTSP completed the demanding installation phase. The LTSP network exists because the right people in critical management positions were willing to take a substantial risk, key scientists agreed that the issues warranted a large research effort crossing Station boundaries, and through the willingness of Forest Service leadership to commit special funding.

An effort such as this can succeed only with continual commitment and regular feedback. In planning the study network, the founders included a communication plan within the generic study plan. This communication plan defines three committees and their roles in maintaining the LTSP effort.

National Oversight Committee. This committee is chaired by the Associate Deputy Chief for NFS. The National Oversight Committee consists of the appointed Chair of the National Technical Committee and at least one representative from each of the Washington Office staffs of Vegetation Management and Protection Research; Forest Management; Wildlife, Fish, Water and Air Research; and Watershed and Air Management. The primary duties of this group are to: 1) ensure that work is focused on the areas of highest national priority; 2) inform the Chief and Congress of progress and needs; 3) coordinate activities and seek and direct funding for the effort; 4) provide for a review of study proposals; and 5) review, evaluate and incorporate modifications to the proposals.

National Technical Committee. The National Technical Committee members are the Principal Investigators and Regional Soil Scientists involved in the study installation and maintenance and interpretation of study results. This includes members representing the British of Columbia Ministry of Forests and scientists managing other long-term productivity plots with designs and objectives similar to LTSP. This committee is chaired by a Forest Service Principal Investigator appointed by the National Oversight Committee. The primary responsibilities of this group are to: 1) assure that scientific methods are consistent and appropriate to meet program objectives; 2) provide for the establishment of a national database of research results; 3) communicate progress, needs, opportunities, and substantive findings to the Oversight Committee; and 4) coordinate and prepare results for publication. This group meets once per year near one of the field installations (Table 1.) to review progress.

Regional Steering Committee. The Regional Steering Committee (RSC) is composed of the Research Station Principal Investigator(s), Regional Soil Scientist and Regional Silviculturist. This group is charged with identifying study sites, developing collaboration with National Forests, Ranger Districts, and other researchers, preparing specific study plans, and implementation of studies. This committee shares the responsibility of ensuring public awareness of the program with National Forests and Ranger Districts.

For example, in Texas there was public concern about using clearcutting to harvest the timber required to implement the study. The Southern RSC worked with the National Forests & Grasslands in Texas and the public to develop the following alternatives: 1) No Action, as required by NEPA, 1969; 2) harvest 14 patch clearcuts 1.5-2.5 acres in size, with 30-foot borders around plots, and 100-foot borders thinned to a basal area of 30 square feet per acre outside the 30-foot borders; and the competition control portion of the study would not be installed; 3) clearcut approximately 90 acres to allow for the full study installation; and 4) clearcut approximately 40 contiguous acres to allow for half of the study to be installed (no competition control plots). The RSC made several presentations to interested groups about the study and the proposed alternatives. The presentations focused on management needs for the information; the value of the information that would be generated; and that the study was not a study of clearcutting, but used clearcutting as a means of creating needed conditions. Upon evaluation of the alternatives and

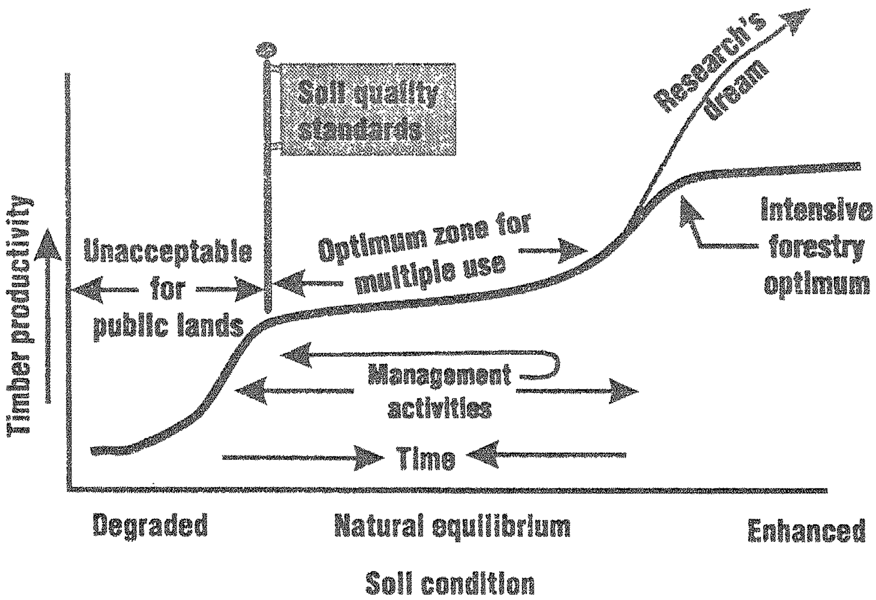

Figure 3.—Idealized relation ship of soil condition quality to productivity of a site. Soil quality standards are established to prevent degradation on the site which would lead to losses of productivity that have been define by law as unacceptable on public lands.

the knowledge value and tradeoffs associated with each, the decision was to adopt Alternative 3 and fully install the study because group selection (Alternative 2) affected management of twice the area and neither Alternatives 1 or 4 met the objectives of the study.

INTERPRETING AND USING RESULTS

Conceptual Framework

As in the inception and installation phases of the long-term soil productivity study, the communication of the results requires NFS managers and research scientists to remain focused on the common goal of validating soil quality monitoring on public lands. This is especially important for LTSP which crosses several administrative layers, is long-term and is producing volumes of useful results. Researchers, silviculturists, soil scientists, and administrators must understand how the results lead to interpretations related to policies and management of public land. The relationship between soil quality and vegetative productivity is the common focal point for LTSP.

In an idealized relationship between soil condition and timber productivity (Figure 3), soil condition is represented by a continuum broken into three zones of soil quality; natural equilibrium, degraded, and enhanced. Unmanaged forest soils reach a natural , dynamic state of equilibrium in physical, chemical, and biological characteristics. In a zone near this equilibrium, timber productivity is not maximized, but other organisms make significant contributions to the ecosystem. This is probably the zone that is optimum for multiple use as defined by Forest Service management policies. In this zone, low intensity management impacts shift the soil condition from the natural state. Without further inputs, the soil condition moves back to equilibrium. Thus, productivity changes associated with the changes in soil condition from normal management activities such as harvesting are small. With increased management intensity, timber production can be increased to a higher level, but possibly at the expense of other uses or resources. Usually this requires the application of several treatments such as tillage and fertilization simultaneously. These may be combined with other practices such as weed control and genetic selection that concentrate the productivity onto a target species. Unfortunately productivity also can be significantly reduced if the soil condition deteriorates beyond a threshold. If management activities degrade the soil below some threshold, productivity can collapse to a new lower level.

The concerns over productivity loss are expressed in legislation such in the National Forest Management Act (USDA Forest Service 1983) and Forest Service policies (U.S. Code of Federal Regulations 1985). These laws and regulations specify research and continuous monitoring to safeguard the land's productivity. As part of the effort to comply with this law, each Region has established soil quality standards meant to detect losses in productivity greater than 15 percent. Thus the soil quality standards, along with other policies, have established thresholds or red flags to prevent the soil from being degraded. These standards are designed to keep productivity from moving into the degraded zone.

Changes to Soil Quality and Productivity

Effects of Management. Preliminary results from the LTSP study illustrate our concepts. In Figure 4, the heights of the loblolly pines, *Pinus taeda* L., planted on the first LTSP site were compared with the heights of the harvested stand for the first 7 years. When low intensity harvesting was

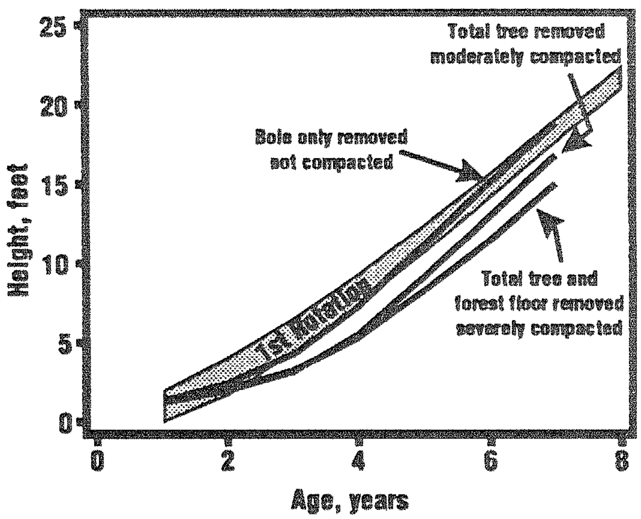

Figure 4.—Height growth over time of loblolly pine on plots treated with three levels of organic matter removal and soil compaction and the estimated height of the previous stand at the same ages. Plots are on the Kisatchie National Forest in central Louisiana.

employed, productivity was maintained at the same level as the original stand. At an intermediate level of harvesting impact, productivity was reduced, but the magnitude of the reduction appears to be getting smaller as the stand ages. Thus, with time, soil condition moves back to its equilibrium. The high impact harvesting treatment reduced height by about 20 percent compared to either the original stand or the low impact harvesting treatment and there does not appear to be recovery at this time. Thus, removal of all above ground biomass followed by severe compaction has degraded the site below acceptable productivity levels. On an operational basis, Region 8's soil quality standards should (and do) prevent harvesting impacts that are greater than the intermediate level. These results are confirmed by studies nearby which show even greater losses in pine productivity in the second rotation following disking or bedding during site preparation (Haywood and Tiarks 1995, Tiarks and Haywood 1996). Soil phosphorus is inherently low on both of these sites so the small amount of phosphorus removed in logging residues appears to have induced deficiencies. The loss in productivity and soil quality can be corrected with phosphorus fertilizer applications.

Losses in productivity are not limited to the timber species, and measurements of other stand components are included as well. On the Croatan National Forest, the number of species and biomass production was quantified by stem form class at 2 years (Table 2.) The number of species was significantly greater on the severely compacted plots where all above ground tree and forest floor biomass was removed compared to the plots not compacted and only the stems were removed at harvest. The greatest increase in number of species and in biomass occurred in the grasses and herb classes. However, the overall biomass on the highly impacted plots decreased by 43 percent compared to the low impact treatments. Increasing numbers of species in the grass and herbaceous classes may be a desirable outcome of management. However, because of the overall loss in productivity, compacting the soil or removing all of the logging residues is not an acceptable management tool and other alternatives should be used.

Results showing these declines are very effective in communicating the importance of soil quality standards to National Forest partners. Large and small private land owners also are concerned about such reductions in productivity as well as the increased productivity from amelioration of timber and other species in these systems. This led to the development of two important ongoing research partnerships with southern industries and universities which are closely linked to LTSP. The VPI/ Westvaco Sustainable Management Study was established with objectives similar to LTSP but with the additional

Table 2.—Number of species and biomass production in understory of stand at 2 years on Croatan National Forest without vegetation control after stem only removal and no compaction or total organic matter residue removal and severe compaction. (From Mellin 1995)

	Number of species		Biomass	
Stem form	Stem only not compacted	Total tree+ forest floor severely compacted	Stem only not compacted	Total tree+ forest floor severely compacted
	-------- number species/plot---------		--------------lbs/acre--------------	
Trees	18	12	974	409
Shrubs	20	20	2872	674
Grasses	7	16	147	1113
Herbs	8	15	12	71
Total	53	63	4005	2267

Table 3.— Ameliorative effect of bedding plus fertilizer with and without herbicide on loblolly pines at age 5 on the Croatan National Forest.

Treatment	height	d.b.h.	volume
	feet	inches	cu ft/ac
Stem only removal not compacted not herbicided	11.4	1.7	29
Stem only removal not compacted herbicided	17.3	3.7	193
Bedded and fertilized not herbicided	19.4	3.3	187
Bedded and fertilized herbicided	21.2	4.5	385

objective of determining if intensive forest management enhances productivity above natural levels (Powers and others 1996) in a sustainable way. Another study (Monitoring Productivity and Environmental Quality in Southern Pine Plantations) involving three forest industries, two universities and Forest Service Research was established to provide linkage between intensive plantation management and LTSP (Powers and others 1996). One of the first products of this LTSP-MPEQ linkage is a data base of biomass and nutrient contents of all the components of stands representative of the loblolly pine range and management intensities.

When possible, ameliorative treatments have been included as part of the LTSP installations. On the Croatan National Forest in North Carolina, herbicide, and bedding combined with fertilization both increased loblolly pine growth compared to the lowest impact treatment in the core LTSP design (Table 3). As the stands further develop, the long-term economic and biological impacts can be assessed. The dramatic differences in tree size and stand structure do demonstrate the impact management can have if rapid development of a stand is desired for species restoration, visual effects and even timber production.

Not all management practices or amelioration treatments have the beneficial effect that is desired and expected when applied. While the intent is to improve soil quality, in practice the operation can reduce soil quality and productivity shown as U-shaped arrow on Figure 3. Stump pulling was included as an ameliorative treatment in some of the LTSP plots in Idaho, but the negative effects on Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, seedlings was greater than the severe compaction treatment (Table 4). Many ameliorative treatments have the potential to impact soil properties in ways that are not initially apparent. Through monitoring, the real effects on these activities can be understood and the practices abandoned when results are not consistently positive. Subsequent research studies can be used to investigate soil processes involved and develop desired alternatives.

Effects of time. Time will push the productivity back to equilibrium for both the positive and negative effects of management, assuming the activity has not caused a permanent change to the site, such as slope failure. The amount of time for full recovery depends on the degree of degradation, soil and site properties, presence of weatherable minerals in the soil, clay type, and tree species. For example, compacted soils will eventually return to their natural state, but the length of time required depends on the depth of compaction, presence and depth of freezing and thawing cycles, and presence of expanding clays. In Mississippi, the upper 5 cm of soil in skid trails would be expected to return to the uncompacted level after about 12 years (Dickerson 1976). However, in Minnesota, where recovery should be faster that in Mississippi because of more freezing and thawing and higher levels of organic matter, soils showed little signs of recovery after 9 years at depths greater than 20 cm. Thus, the depth of compaction is much more important than soil properties, and recovery will be much slower in soils compacted deeper than 30 cm. The relative increase in bulk densities at planting and after a recovery period (Table 4) show some recovery in Minnesota and Louisiana but none on the compacted plots in Idaho. On the Louisiana site, the dominant understory was grasses which should speed recovery compared to the herbicided treatments. The lack of recovery after compaction in the Idaho soils, especially compared to the effects of stump pulling is unexpected. Compaction, as

Table 4.—Relative increase in bulk density at 0-10 cm and tree heights compared to uncompacted plots at three locations

Location	Treatment	Relative bulk density		Relative
		At planting	Post planting[a]	tree height[b]
		------------ percent of uncompacted ------------		
ID	Severely compacted	23	26	-1
ID	Stumps pulled	25	-9	-18
MN	Severely compacted	19	15	-20
LA	Severely compacted not herbicided	9	2	-12
LA	Severely compacted herbicided	9	6	-16

[a]Post planting measurements were made 3 years after planting in ID and 5 years after planting in MN and LA.
[b]Tree species are Douglas-fir in ID, aspen, *Populus tremuloides* Michx. and *P. grandidentata* Michx., in MN and loblolly pine in LA.

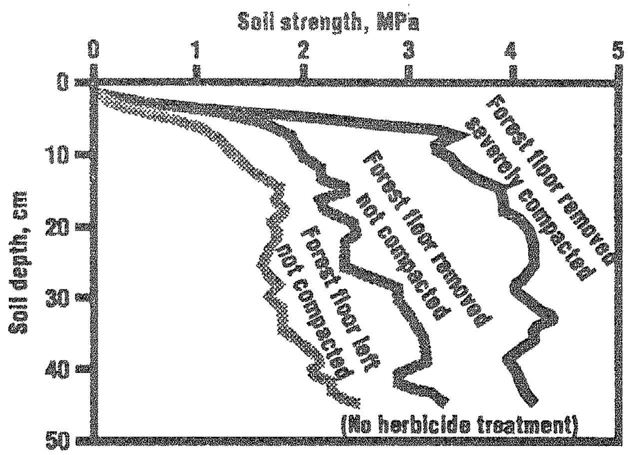

Figure 5.—Differences in soil strength with depth for three LTSP treatments at Challenge Experimental Forest measured in July.

measured by bulk density, also had mixed effects on the heights of Douglas-fir seedlings. These inconclusive results indicate that bulk density may not be the best indicator for monitoring soil properties changed by compaction.

Soil strength measured by a recording penetrometer is a faster way of assessing compaction and is sensitive to changes in bulk density and other soil properties such as water content that affect root growth. For many plants, root growth slows when soil strength exceeds 2 MPa and stops at strengths greater than 3 MPa (Whalley and others 1995). In California, soil strength was increased by removal of the forest floor sufficiently to reduce root growth even when the soil was not compacted (Figure 5). Removal of the forest floor allowed greater evaporation from the soil, raising soil strength as the soil dried. The effects of organic matter levels and soil compaction on other soil and biological process are being measured on various LTSP sites. At each location, ecosystem components related to soil quality at that site are being measured to increase the understanding of the processes involved. Examples of measurements being made at one or more sites include soil arthropod diversity, earthworm populations, types and numbers of ectomycorrhizal roots, soil organic matter quality, water regimes, and soil erosion.

Communicating Results. The committees that were established to plan and implement the study are being maintained and expanded to communicate not only the results of the study, but to aid in the adoption of management strategies. Each year the National Technical Committee meets at one of the LTSP sites along with representatives of one or more of the Regional Steering Committees, the National Oversight Committee, and investigators of studies that have been linked to LTSP. Status of the plots, growth measurements and successes and failures in monitoring efforts are shared and plans for more integrated measurements are finalized. This meeting is informal and facilitates open discussion of all aspects of LTSP.

In all Regions, LTSP results are communicated through the usual technology transfer process of workshops, conferences and publications. The RSC and the Forest Soil Scientist where the plots are located use preliminary findings in revising Forest Plans, to develop better monitoring methods and in ongoing operations. As an example, in the Kings River Ecological Management Area, monitoring forest soil impacts on growth in small openings proved to be very difficult. Instead, the findings on key soil variables from LTSP are used to develop methods of monitoring the soil to estimate effects on growth. In Mississippi, soil redox recording methods developed on the LTSP plots in Louisiana are being used to monitor the recovery of soil disturbed from salvage logging after a tornado. Easy access is being maintained to the sites so they can be used as demonstration areas to test soil quality standards and in the development of monitoring approaches for other resources.

To date, the LTSP study is a superb example on the national scale of the beneficial working relationship that exists at the local level. By networking, the local efforts have been leveraged, providing greater returns that the individual efforts would have. Now the challenge is in maintaining the study, both on the ground and in the Forest Service's thinking. Long-term experiments are like good wines in that they appreciate with age. As of this writing, the plots range in age from 0 to 7 years with the study designed to run 60 to 120 years. Thus, while the results may be tasted at these young ages, they must be treated as peeks at the more full-bodied rewards to come. It is imperative that any interpretations made using early results be treated as tentative and subject to change. Through these and similar efforts at all locations of the LTSP study, results are being applied to "Caring for the Land".

LITERATURE CITED

Blake, G. R.; Nelson, W. W.; Allmaraas, R. R. 1976. **Persistence of subsoil compaction in a mollisol.** Soil Sci. Soc. Am. J. 40:943-948.

Dickerson, B. P. 1976. **Soil compaction after tree length skidding in Northern Mississippi.** Soil Sci. Soc. Am. J. 10:965-966.

Haywood, J. D.; Tiarks, A. E. 1995. **Growth reductions in short rotation loblolly and slash pine in central Louisiana - 10th-year results.** In: Edwards, B., ed. Proceedings of the eighth biennial southern silvicultural research conference, 1994 Nov. 1-2; Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. p. 268-274.

Mellin, T. C. 1995. **The effects of intensive forest management practices on the natural vegetation communities of loblolly pine plantations in North**