Proceedings: Guidelines For Regenerating Appalachian Hardwood Stands

Sponsored by:
West Virginia University
College of Agriculture and Forestry,
Division of Forestry
Extension Service

U.S. Department of Agriculture,
Forest Service
Northeastern Forest Experiment Station
Northeastern Area State and
Private Forestry
In cooperation with Allegheny Society of
American Foresters with assistance from
West Virginia University Conference Office

Morgantown, WV
May 24-26, 1988

Workshop Proceedings

GUIDELINES FOR REGENERATING APPALACHIAN HARDWOOD STANDS

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Allegheny Society of Foresters
SAF Silviculture Working Group
with assistance from
West Virginia University Conference Office

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SAF Publication 88-03

Morgantown, West Virginia
May 24-26, 1988

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1988

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FOREWORD

This proceedings will provide field foresters and landowners with an update of current available information for regenerating Appalachian hardwood stands. We wanted a "state-of-the-art" proceedings for regenerating Appalachian hardwood stands. We asked the authors to make recommendations based on the current literature, their knowledge, and experience. Though many of these papers do provide current information and ideas, landowners and foresters will still have to decide what is best for their situations. From the practical sense, use what information you can and modify what you cannot.

A copy of this Proceedings can be purchased for $12.00 from:

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ACKNOWLEDGEMENTS

We appreciate the efforts of all the authors in writing their papers before the workshop. Through their cooperation, it was possible to have the proceedings available at the workshop. A special thanks to all those reviewing and typing the papers and to the publications staff at West Virginia University for their assistance in printing the proceedings.

To avoid repetition of scientific names of trees, other plants, and wildlife only common names are used in the proceedings. Both common and scientific names are listed in the Appendix.

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REGENERATING APPALACHIAN HARDWOODS: WORKSHOP OBJECTIVES, TERMINOLOGY, AND EXPECTATIONS

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Abstract

The purpose of this workshop is to provide foresters and landowners with information on how to regenerate Appalachian hardwood stands. Topics range from common harvesting methods practiced on public, private, and industrial forest lands to evaluating how seed dispersal is influenced by birds and mammals. This information should help landowners and practicing foresters work together to understand the necessary hardwood regeneration techniques needed to satisfy specific objectives.

Introduction

Is regenerating Appalachian hardwood stands a problem? Cut a tree and something woody occupies its space. Cut 10 trees, an acre, 10 acres or 1,000 acres and the space is filled with vegetation. So regenerating Appalachian hardwood stands is not a problem because space is quickly filled with some kind of vegetation. But what if that space is filled with undesirable species? It is said that 82 percent of the commercial forest land in West Virginia is fully stocked with live trees. However, only 30 percent of this total is acceptable trees (Bones 1978). These are Appalachian forests that were "regenerated" some 60 to 100 years ago.

It seems that regenerating Appalachian hardwood stands that include a "respectable" proportion of growing-stock trees is a problem. The solution? Use regeneration harvesting methods that match the silvical requirements of the desired species. Sounds simple enough. But let's complicate the situation. The landowner says, "You're not going to clearcut any of my woods!" Or the forest user objects to the visual impact of tree cutting! The so-called simple regeneration picture now becomes difficult. Problems occur when landowners want to use a certain harvesting method or foresters want to regenerate a specific hardwood species. The key is not just to regenerate desirable species, but to develop or maintain these desirable species in a favorable position in the crown canopy. Regeneration

methods are needed that accommodate the needs/goals of the landowner and the forester.

The initial key to regenerating hardwood stands is to determine which harvesting practices the landowner will permit. Then the forester and landowner can begin to develop an acceptable management plan for a given property. Usually landowners are concerned about how their forest property looks during and after logging. Landowners like to see wildlife, wildflowers, and/or use trails to bird-watch. Hunting, fishing, walking through their woods, riding a trail bike or a horse are other important values. Often landowners are concerned about making a dollar too. Managing their forest property for some wood products means money either now or in the near future. Although the landowner may receive money for use of the forest property from recreationists, etc., the highest return per acre other than selling the property is usually the sale of timber.

The establishment and development of desirable regeneration is the key to future forest management. Fortunately in the Appalachians, we would have a difficult time stopping the establishment of tree reproduction. Normally there is potential for at least 250,000 woody stems per acre to become established just from available seed in the soil. Following a harvest practice such as clearcutting, there is often 10,000 to 20,000 stems per acre 1 foot tall within 2 years after cutting. Woody species are always present; however, it is the type of available species that is important rather than the number.

The purpose of this workshop is to provide foresters and landowners with updated available information and experience about regenerating Appalachian hardwood stands, that is, cove hardwoods, cherry-maple, and upland oaks. Problems regarding the establishment of hardwood regeneration will be discussed. When known, recommendations will be made to overcome these problems. It is important to recognize that once even-age regeneration practices are applied, the future stand is determined for at least the next 80 to 120 years. The consequences of uneven-age practices are more subtle. It may take years before the structure of the future stand is apparent.

For purposes of communication, speakers were asked to use the Society of American Foresters terminology (Society of American Foresters 1958; Ford-Robertson 1971). A definition is provided if terms deviate from these sources.

Discussion Topics

This workshop should provide foresters and landowners with a better understanding of techniques used to regenerate hardwoods.

We will find out what common harvesting methods are used on public, private, and industrial forest lands in the Appalachians. We also will learn the sources of regeneration and factors that influence these sources. Often stump sprouts make significant contributions to hardwood regeneration. Is this good or bad? Sometimes existing vegetation can interfere with

regeneration through competition for space and/or allelopathic influences. And knowing about plant toxicity can explain some regeneration attempts that failed.

Sometimes deer are a major deterrent to regenerating hardwoods; control methods are usually expensive, and we will examine some of these during the workshop. We will discuss how birds and mammals influence seed dispersal and seedling establishment.

There is a need to discuss how to analyze the regeneration potential of a given site to encourage a more critical evaluation of regeneration problems before any cutting is done. Regeneration is influenced by the microenvironment, and changes in the microenvironment are influenced by different overstory-understory harvesting methods. Herbicides are useful and fire has some potential, even though for many years it was considered undesirable as a silvicultural tool for regenerating hardwoods. Prolific sprouters, such as oak, can survive frequent periodic fires; other species cannot.

Even-age and uneven-age regeneration practices will be examined in terms of expected species composition, wildlife diversity, recreational opportunities, water, and other uses. In many instances even-age and uneven-age harvesting practices look very similar, especially as even-aged stands mature. But the "on-the-ground silvicultural objectives" are different. However, all the silvicultural methods used to establish regeneration for both the even-age and uneven-age management systems have common attributes: trees are cut, reproducing the stand is a major objective, and intermediate practices are used to culture the developing stands. There are other similarities too. How different is a clearcut and a 5-inch diameter-limit where all stems 5 inches d.b.h. and above are cut? What is the difference between thinning a mature sawtimber stand or applying single-tree selection? Both areas look alike. What about a seed-tree cut versus a shelterwood?

How-to guidelines for regenerating cove hardwoods, cherry-maple, and upland oak stands will be presented. An update of oak regeneration on good to excellent sites will be reviewed. There is a success story about regenerating oak too! Insect problems and concerns with oak seedlings and acorns will be discussed. And we will look at how the gypsy moth influences regeneration of the Appalachian hardwood types.

Alternatives to clearcutting and selection practices will be examined. Many even-age regeneration practices are visually undesirable, and the classic uneven-age regeneration practice (single-tree selection) has not been used in the woods to any great extent. Diameter-limits are very common throughout the Appalachians, but foresters normally do not recommend using this practice. Are there ways to apply the diameter-limit to make it more acceptable to foresters?

We will look into the economics of planting hardwoods and ideas on supplementing forest sites by planting desirable species. Foresters and

landowners will be given guidelines including costs to remove nonmerchantable sapling and pole-size trees when applying an even-age method.

The significance of site productivity and regenerating hardwoods is often taken for granted, but site is one of the major factors in regeneration success or failure. We will discuss site productivity and guidelines for locating site changes in the field.

Summary

Information presented at this workshop should provide some very specific directions for regenerating Appalachian hardwood stands and thus help practicing foresters and landowners understand hardwood regeneration techniques and problems. They will also know how certain regeneration practices can be used to satisfy a specific objective and can then begin to plan to manage their stands based on objectives that are attainable, practical, and result in mutual benefits to all concerns.

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Bones, James T. 1978. The forest resources of West Virginia. Resour. Bull. NE-56. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 105 p.

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REGENERATING APPALACHIAN HARDWOODS: THE CURRENT SITUATION ??

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ABSTRACT

The relative quantity of regeneration cutting in the Appalachain Region is described, along with an indication of landowners' understanding and attitudes regarding regeneration cutting practices. Several foresters were asked to complete a questionnaire regarding the type of regeneration they think is occurring in their respective geographic areas. These subjective observations are compiled for the oak, cove hardwood, and cherry-maple types.

Introduction

The most significant characters in the above title may be the two question marks. They indicate the uncertainty we have regarding regeneration of the Appalachian hardwood species. We have no definite information based on sound data to share with you. Unfortunately, until recently, there was not a good region-wide inventory of the species composition of regenerating stands after harvest cutting. However, we do not intend to let the lack of a concrete information base keep us from at least indicating what we think may be happening in the Appalachian hardwood forest.

Information from Forest Resource Inventories

Unpublished data from the forest resource inventories of West Virginia, Pennsylvania, eastern Kentucky, western Maryland, and the Hill Country of Ohio, indicate that approximately 28 percent of the forest (all types) needs regeneration cutting, and another 39 percent needs intermediate cutting. Approximately 17 percent of the area has received some degree of disturbance due to cutting between the last inventories (an interval of about 11 to 14 years). About 35 percent of the oak-hickory type received some cutting since the last inventory (17 percent of which was clearcutting and the remainder some type of partial cutting).

In just Pennsylvania and the Hill Country of Ohio, approximately 30 percent of the Appalachian hardwood types (oak, cove, and cherry-maple) received some type of cutting. Of this total, 25 percent is clearcutting while the remaining 75 percent is some type of partial cutting that may or may not result in the establishment and development of regeneration. Comparing this harvesting activity with needs reveals we have more acres needing cut than are being harvested. Approximately 29 percent of the area needs regeneration, and an additional 30 percent needs intermediate cutting.

In the past, the U.S. Forest Service Forest Inventory and Analysis Unit (FIA) has been most interested in the overstory component of the forest, especially with those trees that would contribute to growing-stock volume. Data were collected on saplings or seedlings only if no trees larger than 5" dbh were present on a point, and then it would be limited. Such a procedure precluded estimation of numbers of small trees. Tallying of seedlings, saplings, and shrubs began in 1980 on five milacre-acre reproduction plots for each ground plot. This permitted estimating the number of small trees, but the plot size was too small to suit other needs. Currently, FIA is planning to enlarge the reproduction plot to a 6-foot radius (1/385-acre). Reproduction will be tallied on all forested plots regardless of stand-size class (i.e., sapling/seedling, poletimber, and sawtimber). On these plots, all trees and shrubs at least one foot tall will be tallied by species. Because of time and species identification constraints, smaller regeneration will not be tallied. Although this new system is still in the planning stages, FIA is consulting with knowledgeable research and practicing foresters, and is moving toward getting a better handle on advance forest regeneration.

Cutting Practices--Landowners' Opinions

Landowner surveys conducted by the Forest Inventory and Analysis Unit (FIA) of the Northeastern Forest Experiment Station provide us with owners' thoughts regarding harvesting practices (Birch and Dennis 1980; Birch and Kingsley 1978; Kingsley and Birch 1980; and Birch and Powell 1978). Landowner responses to the following question indicate the type and amount of regeneration cutting currently being carried out in the central Appalachian hardwood region (Table 1).

How were your trees selected for harvesting?
(Please check only the method that accounted for the greatest volume, if more than one method was used.)

Check One

/ / Selection (Only pre-selected market trees were removed.)
/ / Diameter limit (Only trees over a minimum diameter were removed.)
/ / Clearcutting (Most or all the trees on a given area were removed.)
/ / Land clearing (Trees were harvested incidental to clearing the land for a use other than woodland.)
/ / Other (Please specify _____.)

/ / Don't know method used.

Table 1. Landowner Opinion of Regeneration Cutting Practices Applied on Their Land

State	Cutting Practice		
	Selection	Diameter limit	Clearcutting
	Percent[a/]		
Pennsylvania	43	45	12
West Virginia	31	55	14
W. Maryland	24	40	36
E. Kentucky	27	61	12
Ohio Hill Country	32	47	21
Total	35	51	14

[a/] (Acres in cutting practices/acres in all three practices) x 100.

Note: When evaluating this information, remember this table is a description of what the landowners think is being done on their property. Their concept of the three cutting practices (selection, diameter limit, and clearcutting) may be very different from our classical definitions of the terms. For example, selection cutting to a landowner may be any cutting where some trees are cut and others are left. Some of this type of "harvest cutting" might not establish regeneration, while other cuts may approach a commercial clearcut. Nonetheless, this is the best indication we have of the relative quantity and type of cutting occurring in these areas at the present time.

Survey responses also provide an indication of landowners' understanding and attitudes regarding regeneration cutting practices. If landowners believe a cutting practice is always bad, they are less likely to use it. Responses to true or false statements are summarized below:

True/False Statement #1: Once a forest is cut it will not grow back unless planted.

Answer: False

	Percentage of Landowners Who Answered			
Geographic Area	Correct	Incorrect	Did Not Know	Did Not Answer
Pennsylvania	58	18	8	16
Western Maryland	76	14	4	6
West Virginia	57	24	9	10
Eastern Kentucky	26	29	14	31
Total	53	22	9	16

True/False Statement #2: Clearcutting is always bad forestry.

Answer: False

	Percentage of Landowners Who Answered			
Geographic Area	Correct	Incorrect	Did Not Know	Did Not Answer
Pennsylvania	34	30	20	16
Western Maryland	25	56	9	10
West Virginia	25	43	20	12
Eastern Kentucky	15	24	18	43
Total	28	32	19	21

True/False Statement #3: Selective logging is always good forestry.

Answer: False

	Percentage of Landowners Who Answered			
Geographic Area	Correct	Incorrect	Did Not Know	Did Not Answer
Pennsylvania	9	56	16	19
Western Maryland	1	72	17	10
West Virginia	11	52	24	13
Eastern Kentucky	4	39	25	32
Total	8	52	20	20

As we can see from the responses to the true/false statements, there is a need for landowner education regarding regeneration practices. Unless we are able to educate the clients we serve, we will be constrained by their perceptions of what good and bad regeneration practices are. This need is even more critical since the forests in the Appalachian area are maturing, and there will be a greater need for regeneration cutting in the future than we have experienced in the past.

Response to Regeneration Survey--Foresters' Opinions

We were unable to find a suitable database describing the species composition of stands that have received various types of regeneration cutting. Rather than rely solely on our own observations over a widespread geographic area, we decided to solicit, via a questionnaire, the opinions of several foresters regarding their experience with regeneration cutting practices in their respective areas.

The questionnaire information we received is for oak, cove hardwood, and cherry-maple types in Pennsylvania and West Virginia. Attention is focused on stands 8 to 10 years old, since the species composition of stands that are only 2 to 3 years old is subject to dramatic change. It is recognized, however, that species composition at 8 to 10 years is also subject to change, and what we are currently observing may differ from what foresters will see in 50 to 100 years.

The three following illustrations were prepared after summarizing the questionnaire responses (Figures 1, 2, 3). For several of the regional areas shown, there are two series of species indicated. The first line, 1), indicates species perceived to be regenerating under relatively open forest conditions, such as in clearcuts, shelterwood cuts, and diameter limit cuts down to 12" dbh. The second line, 2), indicates species perceived to be regenerating under relatively shady conditions, such as selection and 16" dbh diameter-limit cuts.

Based on these illustrations:

1) There appears to be a general increase of red maple. In central Pennsylvania, the occurrence of red maple on oak sites seems to be increasing. However, in adjacent northwestern Pennsylvania on cherry-maple sites where red maple is a desirable species, regeneration is relatively difficult to establish.

2) Oak seems to be regenerating on drier oak sites in southern and western West Virginia, while stands in the eastern panhandle are regenerating to red maple.

PREDOMINANT REGENERATING SPECIES
8-10 YEARS AFTER CUTTING

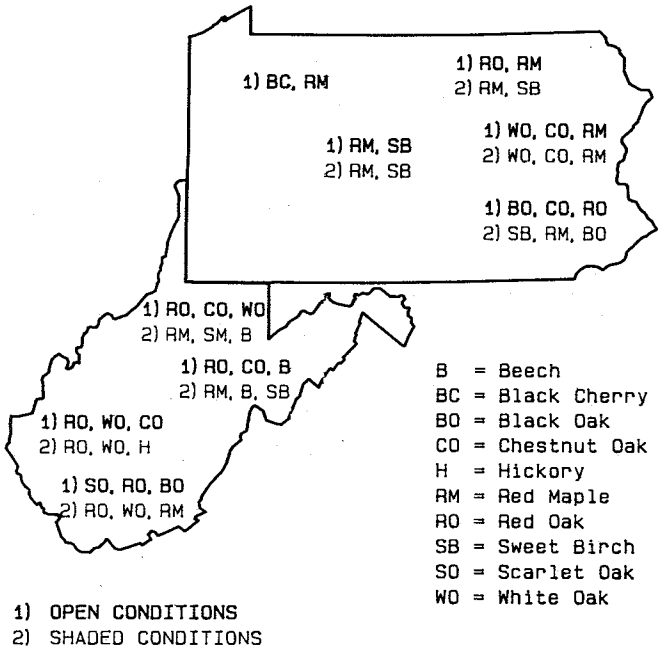

Figure 1. Summary of regeneration survey--oak.

3) Sweet birch seems to be appearing with greater prominence than we currently see in older stands. This is especially true in areas that have been heavily defoliated by gypsy moth. However, we expect it to lose its competitive position as the stands grow older.

4) White ash appears to be regenerating in eastern Pennsylvania, while it is not in north central and western Pennsylvania. One thought is that the past several years of gypsy moth defoliation has increased the supply of browse to such a degree that white ash, a preferred browse species, is now able to survive. If this is so, how long will these conditions persist?

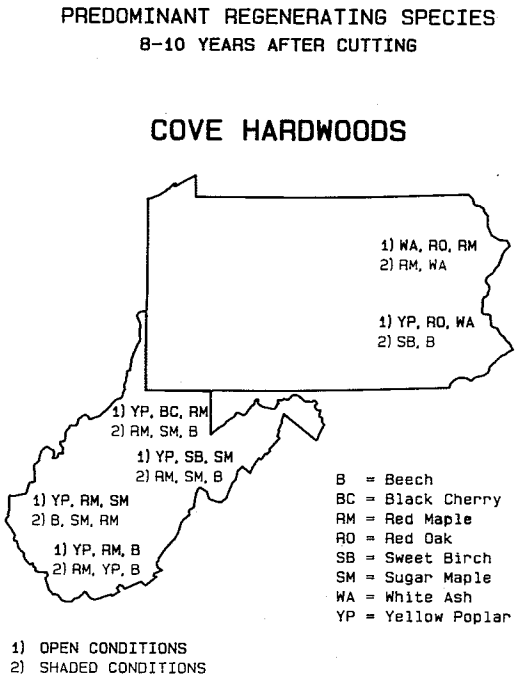

Figure 2. Summary of regeneration survey--cove hardwoods.

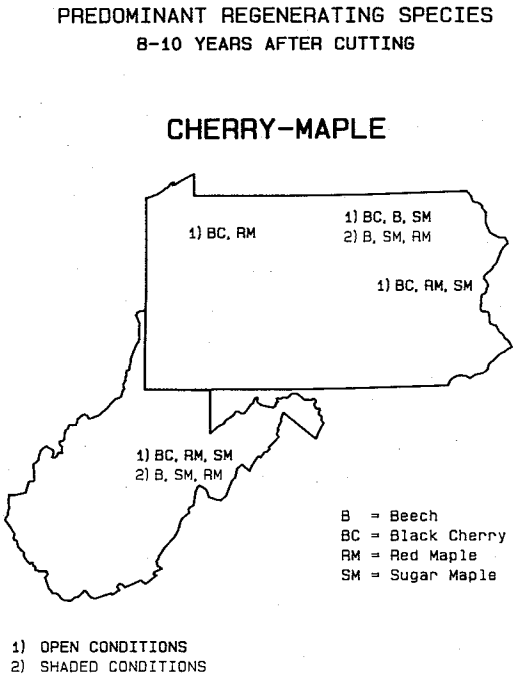

Figure 3. Summary of regeneration survey--cherry-maple stands.

Letters were received from Robert Brooks, Timber Staff Officer on the George Washington National Forest, and Wilbur E. Wolf, Jr., District Manager for The Glatfelter Pulp Wood Company. Their comments are so relevant, we decided to include the contents of their letters:

Robert G. Brooks: "Rather than send your questionnaire back, I think it may be more informative and helpful to you to narrate some of my observations. I have been on the George Washington, in timber management, for about 17 years. That is enough time to have observed the "birthing pains" of even-aged management on this Forest, even though in the early time, 1965-1970, I was not present.

The initial period of even-aged management coincided to a degree with an initial period of herbicide use for site preparation. In some instances this combination resulted in a satisfactory job of regeneration. In others, because of certain characteristics of the stand being regenerated, a less than satisfactory regeneration resulted. Almost 100 percent of the harvest was by clearcutting either by removal of the entire merchantable stand, sawtimber and pulpwood, or removal of the sawtimber with the poles and stems not merchantable for sawtimber removed with herbicides applied in a variety of ways.

It was quite evident when I arrived on the scene in late 1970 that the two treatments were giving distinctly different results. As you probably guess, the stands that were cut and harvested with minimal or no herbicide treatment responded with a tremendous flush of sprout growth. Those with only the sawtimber harvested followed by herbicide treatment of the residual showed spotty regeneration, as a general rule.

There were some complicating factors and some mitigating factors---the bad news and the good news. First, the "good" news. The average oak site index, and the Forest is largely oak, is probably not more than the low sixties. This relatively low site often times gave a great number of stumps suitable for sprouting and at times there was a sufficiency of oak advance regeneration to restock the stand, regardless of what happened to the poles and smaller size class. Now the "bad" news. In the areas where there was not a pulpwood market, the harvest tended to go where there was sawtimber---to the better sites. These sites sometimes had light seeded species such as yellow-poplar to help regeneration, sometimes they didn't. We found also that striped maple in great abundance often occupied the better sites, effectively precluding any large amount of advance oak regeneration. It was this general combination, with the use of

herbicides that produced less than adequate regeneration on occasion. Oh yes, I almost forgot the deer. The G.W. is blessed/cursed with a large deer herd that can have a detrimental effect on regeneration, both advance and following harvest.

Following the initial period of observation several things have happened. Herbicide is virtually a no-no in hardwood regeneration. We have found a virtual dependency on stump sprouts. The sprouts are encouraged by our primary method of site preparation which is chainsaw felling of unwanted residual stems. The deer problem/opportunity is still with us and sprouts furnish a great deal of browse. Incidently, we have relied on chainsaw site prep since about 1973 or so. It gives a much cleaner, more completed look in addition to the silvicultural considerations.

Secondly, the pulpwood market has expanded to almost all the Forest. There are four mills, all using hardwood totally or a high percentage, within trucking distance of the Forest. Fuelwood has reappeared to become a relatively major market.

Thirdly, we have learned to recognize that some conditions, namely abundant striped maple, lack of advance regeneration, and large, mature timber, preclude successful regeneration. There is not a clear answer to the striped maple condition but Garlon 4 applied as a basal spray (thinline) with Cidekick as a surfactant and diesel fuel as a carrier shows good promise.

We are working with Don Beck and Dave Loftis. They agree with herbicide treatment applied prior to harvest. If adequate regeneration numbers are established, this allows it to develop to the point to which it can compete. There is no assurance that if adequate numbers are not present that removal of the striped maple or other tolerant midstory will allow oak regeneration to become established. Fourthly, an effort is made to make regeneration areas expansive enough to blunt the capacity of the deer to overwhelm the regeneration effort.

To answer your questionnaire more directly, we do not have summarized species composition other than on a stand by stand basis. We have no experience in cherry-maple type.

Subjectively, in the cove hardwood types, if there is a yellow poplar present it will most likely be the most abundant commercial species; second, the better oaks; third, the poorer oaks. I might point out that we do not consider red maple or black locust a desirable species. If one were to include them they would rank first or second.

In the oak types, including those sites below the "best" category of about SI 70 for oak the poorer oaks are first in occurrence; pines, either yellow or white second, and the better oaks third. Same comment on maple and black locust. Also, subjectively I cannot tell much difference in terms of regeneration composition between clearcuts and shelterwood cuts. Shelterwood cuts don't seem to develop new advance regeneration. In either case you have to live with what is there - be it advance regeneration, buried seed, or stump sprouts.

The Forest is just embarking on group selection. Time will tell how well this technique works in terms of regeneration.

Arlyn, after this long dissertation, which I hope is of some value to you, I would summarize this way:

--- Our regeneration efforts are successfully stocked most of the time, like the high 90's in percent.

--- There is a variety of both commercial and non-commercial species in the areas.

--- Some questions we don't yet have the answer to, such as handling the tolerant understories.

--- As with everyone else, the best sites give the most regeneration problems.

--- We have learned a lot since the advent of even-aged management."

Wilbur E. Wolf, Jr; The Glatfelter Pulp Wood Company: "The question you asked in your August 10 letter is rather difficult to answer with a fill in the blank type answer format. My experience has been mostly in the oak/hickory type. In certain high site areas it may border on being cove hardwoods but I continue to call them oak sites. Generally on the drier sites SI 45-60 silvicultural clearcutting or shelterwood will produce a preponderence of oak reproduction, heavy to chestnut oak. The higher the site, the more likelihood in general, of having a sizeable red and black oak component. Unless there is a well established understory of black gum or dogwood the oak will come through. On moister sites 60+ the oak component in the reproduction decreases and the black birch, red maple, sugar maple, yellow-poplar component increases. A shelterwood overstory with 60 percent crown cover may inhibit, to a degree, the black birch and red maple and allow more oak to develop. In any situation where a white pine seed source is present white pine has been increasing as a percentage of total stocking.

> Diameter-limit cuts, and commercial clearcuts tend to release an intermediate layer of undesirables such as black gum, crooked red maple, etc. which dominates the lower canopy and effectively stifles the development of reproduction.
>
> I can say, in general, the higher the level of management, understory control, etc., the more likely there will be a sizeable oak component in the future stand. In addition when we do get a species like red maple it will generally be of better form than those in "non-managed, just-harvested" stands.

We also received input from **Richard Burt**, Assistant Timber Staff Officer on the Hoosier National Forest. Following are his comments concerning 1,801 plots that were visited in 74 five- to seventeen-year-old clearcuts on the Hoosier.

> "In just looking over the data, it is obvious that species composition changes rapidly. I'm not sure the present compositions will be any indication of species composition late in the rotation. My personal guess is that many of the intolerants will drop out and composition changes won't really slow down until about 50 years or so -- a good field for speculation! The species I gave you for the oak type (yellow-poplar, black cherry, elm) will undoubtedly change, and I feel the oak component, now a relatively small percent of most stands, will become significant. Probably not so on coves".

Conclusions

So what does all of this mean? On large land ownerships, both public and private, where investments in regeneration are to some degree being made, we can find examples of foresters being able to influence the species composition of regenerating stands. The Glatfelter Pulp Wood Company and the George Washington National Forest are good examples. However, even there, our degree of influence is certainly limited by site, species composition, past management, environmental concerns (use of herbicides), and availability of investment funds.

On the private non-industrial forest, there has been little investment in regeneration. Most stands are regenerating under relatively shaded conditions (what landowners have described as selection and diameter limit cuts) where there has been very little, if any, control of undesirable mid and understory competition. In many of these stands, we have to a large degree eliminated fire and grazing as influential factors. On many of the definite oak sites (generally poorer sites), we are still getting oak

regeneration. Looking at the Appalachian Region as a whole, on the better sites there is probably a general transition occurring from oak to species like yellow-poplar, red maple, sweet birch, sugar maple, and blackgum. We say "probably", because we really do not know. Remember, the information we have presented is very subjective. We look forward to the availability of regeneration information that will result from the new system FIA is now planning.

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SOURCES OF HARDWOOD REGENERATION AND FACTORS THAT INFLUENCE THESE SOURCES

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ABSTRACT

Reproductive characteristics of the more important Appalachian hardwood species are reviewed, and species are categorized by similarities in these characteristics. Frequency of good seed production varies among species from nearly annual to very sporadic, but many species produce seeds that remain dormant but viable in the forest floor for many years, assuring a fairly constant seed supply. Few species can be classed as pioneers--only yellow-poplar, sweet birch, and black locust (through root suckering) become established in large numbers following clearcutting. All other species rely to some degree upon becoming established as advance growth. The ability of advance-growth seedlings to survive and grow rapidly following release from overstory shading depends upon their size and vigor. Larger seedlings respond better in all species, but black cherry is the best adapted to respond when small (2 to 6 inches); at the other extreme are the oak species, which must be at least 4.5 feet tall to respond well to an overstory release. Most species also have the ability to produce stump sprouts; these have the potential of producing sound, high quality stems.

Introduction

Every tree species has evolved what can be termed a "reproductive strategy"--a unique set of characteristics that facilitates establishment under a certain set of conditions. The large number of species that comprise the Appalachian hardwood forest type span the range from pioneer species to extremely shade-tolerant ones. Most of the basic types of reproductive strategies possible in trees are represented among these species, giving a variety of sources of reproduction (e.g., stump sprouts, advance-growth seedlings, seed stored in the litter). Silviculturists must be aware of the details of each species' reproductive characteristics in order to design the most efficient regeneration treatments that take advantage of these adaptations rather than try to succeed in spite of them.

This is especially true when trying to favor certain desirable species over competitors which have many characteristics in common.

The purpose of this paper is to review the reproductive characteristics of the most important species of the Appalachian hardwood forests. Later papers in this symposium will deal with the complexities of designing silvicultural treatments for a variety of key species on different sites, and will focus on such issues as the role of planting and the relative quality of sprouts and seedlings, which will be discussed only briefly here.

Review of Possible Sources of Reproduction

The sources of reproduction occurring among the Appalachian hardwood species can be divided into those arising directly from seed and those originating as sprouts from dormant vegetative buds on already established trees.

Seedlings

For seedlings, an important distinction among sources lies in the way that a seed or seedling reaches a site opened by harvesting. Seed of some species can be blown into the cut area from adjacent trees, and germinate in open conditions; however, very few of the Appalachian hardwood species have this ability. A number of species overcome this need for wind dispersal by producing seeds that remain dormant in the forest floor beneath the overstory, where conditions are not conducive to germination. They can then germinate when moisture, temperature, and light conditions become favorable, such as following a cutting. Seedlings of many species also germinate beneath a partial or full overstory and exist as suppressed advance growth, growing very little, but able to respond to release when the overstory is removed. The ability of advance-growth seedlings to respond to release depends on their size, with the minimum size necessary varying considerably among species. These last two strategies (extended seed dormancy and advance growth) provide means of storing regeneration on the site in different forms, eliminating the need to schedule cutting to coincide with a heavy seed crop. The first strategy (wind dispersal) depends upon this timing, since competing vegetation will often quickly dominate a site if regeneration of desired seedlings is delayed.

Stump Sprouts

Sprouting from vegetative buds is very common among the Appalachian hardwood species. Most of the species sprout vigorously from buds located on the root collars of stumps. This mode of regeneration has long been considered to produce poor quality stems compared to seedlings of the same species, mainly because of a high incidence of decay and breakage in stump sprouts.

However, it is now clear that all stump sprouts do not suffer equally from this problem, and many of the fine trees in second-growth stands originated as sprouts. The incidence of decay and breakage increases with the size of stump and the height on the stump from which the sprout originates, with the latter being the more important factor. Sprouts that originate at or near the ground line are likely to survive to maturity with the potential of producing a high quality stem (Wendel 1975; Lamson 1976).

Seedling Sprouts

Seedling sprouts are another form of vegetative reproduction; they are biologically identical to stump sprouts, with the only distinction being that they originate from small stumps (less than 2 inches in diameter). While this exact size is arbitrary, the distinction is quite important, because the small stumps are quickly covered with callus tissue, such that no open wound is present for infection. Because they often develop after the seedling stem dies or is broken off at ground level, there is no problem of sprouts originating high on the stump. Thus, seedling sprouts tend to be free of the bad qualities that can occur with sprouts from large stumps. In fact, they are best considered in conjunction with advance-regeneration seedlings, since they usually occur in abundance when seedlings are damaged during logging operations. They tend to be even more desirable than seedlings, because seedling sprouts have established root systems and grow faster than the original seedling shoots, so the stems are often straighter. This characteristic has led to trials of mowing advance growth just before overstory removal in order to produce sprouts, but enough are usually created during logging that this generally does not appear to be necessary.

Root Suckers

Finally, a few species sprout from adventitious buds produced on the roots; these sprouts are generally referred to as root suckers. They do not necessarily form poor quality stems compared to seedlings of the same species, but among the Appalachian hardwoods, root suckers do not occur with the more desired species in any case.

Categorization of Species by Regeneration Characteristics

It is not possible to assign each of the Appalachian hardwood species to one of these sources of reproduction, because most exhibit many combinations of reproductive strategies. Each species has a unique set of characters, so any placement of them into categories will be artificial and debatable. However, some categorization is still needed to generally organize the confusing array of species and reproductive pathways that exists. The division into three basic categories used below was developed by Spurr and Barnes (1980); they used the terms "pioneer", "gap-phase", and "extremely shade-tolerant" to describe the three patterns of regeneration. The term "advance-growth-dependent" (Smith 1986) is used below in the names of the

second and third groups to stress that characteristic of species in those groups. The important species in each group are discussed below, with characteristics of these species summarized in Table 1.

Table 1. Summary of several reproductive characteristics of 14 Appalachian hardwood species.

Species	Seedling shade tolerance	Mininum size acceptable advance growth	Seed dormancy	Wind dispersal	Soil[a/] scarification
		---Feet---	--Years--	--Feet--	
Pioneer Species					
Yellow-poplar	Intolerant	---	>3	300	Yes
Sweet birch	Tolerant	---	Several	>300	Yes
Black locust	Very intolerant	---	Several	None	No
Advance Growth Dependent Species of Moderate Shade Tolerance					
Black cherry	Intolerant	0.5	>3	None	No
Red maple	Tolerant	2.0	None[c/]	300	Somewhat
White ash	Intermediate	2.0	>3	300	Somewhat
Basswood	Tolerant	2.0	>3	Limited	Yes
Red oak	Intermediate	4.5	Overwinter	None	No
White oak	Intermediate	4.5	None	None	No
Hickories	Intermediate	?	Overwinter	None	No
Black walnut	Intolerant	?	1	None	No
Advance Growth Dependent Species of Extreme Shade Tolerance					
Sugar maple	Very tolerant	2.0[b/]	Overwinter[d/]	300	No
Beech	Very tolerant	2.0[b/]	Overwinter	None	No
Hemlock	Very tolerant	2.0[b/]	Overwinter	Wide	Yes

[a/] Germination aided by scarification of exposed mineral soil.
[b/] At minimum should be sapling size (1.0 to 4.9 inches dbh) to reach overstory in new stand.
[c/] Majority germinate soon after falling, but some may remain dormant 1 year.
[d/] Majority germinate the first spring after falling, but some may remain dormant 1 to 2 years.

Pioneer Species

Yellow-Poplar, Sweet Birch, Black Locust

The only species of the Appalachian hardwoods that truly fits this description is yellow-poplar, but sweet birch exhibits enough of the characteristics that it is included here as well. Both species have a number of the traits common to pioneer species that enable them to invade open sites. They both produce seed abundantly, with good seed years occurring frequently. Heavy birch seed crops are produced every 1 to 2 years (Fowells 1965), with heavy crops of yellow-poplar being described variably as nearly annual (Beck and Sims 1983) to somewhat irregular (Fowells 1965). Seed is dispersed by wind, with yellow-poplar being blown for 4 to 5 tree heights; the small seeds of sweet birch can probably be blown even further. In the case of yellow-poplar, seed remains dormant in the forest floor for at least 3 years in abundance, and some remains viable up to 8 years (Clark and Boyce 1964). The dormancy of sweet birch seed is not known precisely; most germinates after the first winter, while some may overwinter perhaps for several years (Fowells 1965; Beck and Hooper 1986). Exposure of mineral soil aids the germination of both species, especially for birch because of the small seed size. Both have very fast juvenile height growth rates and can outgrow most competitors when growing in full sunlight. However, the ability of yellow-poplar to compete with other vegetation is affected by the timing of germination. If cutting occurs by mid-spring at the latest, yellow-poplar will germinate early enough to compete successfully with the flush of weeds that also invades the site. If a cutting takes place in the late spring or summer, yellow-poplar germination is delayed and on some sites the seedlings will not be able to grow fast enough to compete successfully (Trimble and Tryon 1969).

Although black locust lacks some of the characteristics of seed production and dispersal common to pioneer species, it fits best in this category anyway. This is because it generally reproduces by root suckering from a cut or injured tree (Fowells 1965). Locust root suckers are very intolerant and grow rapidly in height, so they compete well in full sunlight. Thus, black locust acts as a pioneer, except that it cannot readily be dispersed onto a new site if it does not already exist there.

The pioneer status of these three species is most apparent following clearcutting. Seedlings of most species decline in numbers following clearcutting, as smaller advance-growth seedlings die from exposure, but yellow-poplar, sweet birch, and black locust increase in numbers and dominate in height development (McGee and Hooper 1970; Beck and Hooper 1986). Only stump sprouts of other species can match the height growth of these species when growing in full sunlight.

Yellow-poplar and sweet birch both have alternate modes of reproduction. Yellow-poplar can germinate beneath a partial overstory and exist for a short period as an advance-growth seedling, although this process is not crucial to its establishment as it is for many other species. Sweet birch

is unusual for a species exhibiting many pioneer characteristics, in that it is tolerant of shade as a seedling, and can regenerate beneath a fairly dense overstory canopy. Both species can also sprout from seedlings or stumps.

Advance-Growth-Dependent Species of Moderate Shade Tolerance

The majority of Appalachian hardwood species fall into this category. The ecological term "gap-phase" that can be applied to these species refers to the usual mode of reproduction in unmanaged forests where seedlings are established beneath small gaps in the canopy caused by windthrow or other natural disturbance. They survive in the understory as advance regeneration until another disturbance enlarges the gap and releases them. The overstory shade is necessary with these species to moderate the temperature extremes and droughty conditions that occur in the upper soil layers in exposed conditions. These kinds of disturbances can be duplicated in shelterwood cuttings, but may occur following thinnings or other partial cuttings as well. These species can be thought of as advance-growth-dependent (even though they do not actually rely completely upon this pathway) to emphasize the fact that abundant regeneration is dependably obtained only from vigorous advance growth. The species in this group range from intolerant to tolerant, with only the extremes (very intolerant and very tolerant) being excluded. There is considerable variation in details of regeneration mechanisms within this category, and three subgroups can be recognized.

Black Cherry

The first subgroup consists only of black cherry, which is the closest of the advance-growth-dependent species to having pioneer characteristics. Frequent cherry seed crops occur every 3 to 4 years (Fowells 1965), and the seed can remain dormant in the litter for 3 years or more (Trimble 1975). Seed dispersal is by birds, so it is more limited than wind-dispersed pioneer species. This species also differs from a true pioneer in that germination is greatly enhanced by partial shade. Unlike yellow-poplar, black cherry seedlings become established in much greater numbers beneath a canopy as compared to open conditions.

In Allegheny cherry-maple stands, the greatest numbers of cherry seedlings become established beneath a fairly heavy overstory (approximately 2/3 of full canopy) (Marquis 1979). These seedlings are intolerant of shade and can survive only a few years beneath a dense overstory, but they are able to respond to overstory removal when fairly small. Seedlings smaller than 2 inches in height do not survive well after overstory removal, but those that have reached 6 inches in height and larger have good survivorship and grow very rapidly in height upon release (Marquis 1982). In contrast, black cherry is sometimes able to become successfully established following clearcutting; this was found to be the case on Appalachian mixed hardwood sites in West Virginia (Trimble et al. 1986). In these cases, most germination is probably from dormant seed stored in the forest floor.

White Ash, Basswood, Red Maple, Sweet Birch

The next subgroup includes white ash, basswood, and red maple. Seeds of ash and maple are wind-dispersed for a moderate distance, but basswood seed dispersal is very limited. Scarification is beneficial for the moderate-sized seeds of these species, but is not critical for germination. Basswood produces good seed crops every 1 to 2 years, with white ash being more irregular. Seed of both can remain dormant up to 3 years in the litter (Trimble 1975). Nearly all red maple germinates the first season, but this is not especially limiting to reproduction because large crops are produced almost every spring. These species can sometimes invade open sites under the right set of conditions of site quality and seed source, but this generally does not provide dependable regeneration. Dense reproduction is only obtained beneath the shelter of a partial overstory. In general, small advance-growth seedlings of these species do not respond as well to release as black cherry. Marquis (1982) found that survival was good for red maple and white ash seedlings at least 6 inches tall, but recommendations based on research with many species in northern hardwood forests are that seedlings should be a minimum of 2 feet tall in order to dependably show good survival and response (Tubbs 1977).

In addition to behaving as a pioneer species, sweet birch can be included with these species because it is tolerant of shade (similar in degree to red maple and basswood) and can become established under a fairly dense overstory. It often germinates on decaying stumps and logs, and thus is not limited by the lack of a mineral soil seedbed on relatively undisturbed sites.

Oaks, Hickories, Black Walnut

The third subgroup consists of species with heavy, animal-dispersed seed--the oaks, hickories, and black walnut. Regeneration of these species is more irregular and difficult than of any other group. Seed production of black walnut and hickory is somewhat irregular, with good seed crops occurring every 2 to 3 years. Good acorn crops are produced very sporadically in all the important oak species, occurring at 2 to 10 year intervals (Watt 1979). During years with poor seed production, predation by insects and mammals may eliminate the entire crop (Watt 1979). The seed of these species is dispersed only as far as small mammals carry them, and best germination occurs when seeds are buried beneath the litter, bringing them in contact with mineral soil.

Of the "gap-phase" species, the oaks are the most dependent upon the advance regeneration pathway. Oaks have slow initial height growth even with full sunlight, because much of the early growth goes into establishing the root system. Thus, they do not compete successfully with many intolerant species. Because they are only moderately tolerant of shade, the seedling shoots cannot survive for long periods beneath an overstory. However, the oaks have the ability to produce sprouts repeatedly when the shoot dies back or is damaged, so they can persist for extended periods in the understory as

seedling sprouts (Watt 1979). As with other species, oak advance-growth seedlings or seedling sprouts respond better to release from overstory shading if they are large and vigorous. The minimum size is greater for the oaks than for other species, although; only those that have reached a height of 4.5 feet or greater have a high probability of surviving and competing well with other vegetation upon release (Sander 1972). Furthermore, seedlings with flat-topped crowns do not show rapid growth compared with more vigorous stems having definite recognizable leaders (Carvell 1979). Obtaining this large, vigorous, oak advance growth is the major stumbling block in oak regeneration. Increasing the light levels reaching the understory is the major way of stimulating height growth of oaks, but this usually produces conditions that are also favorable to many faster growing competing species.

Less information on natural regeneration characteristics is available for hickory and black walnut, because hickory is not a highly desired species, and black walnut is so desirable that most research has dealt with plantation management. In general, these species have many of the same root and shoot growth characteristics as oak. Black walnut is even less tolerant, so it is necessary to provide full or nearly full sunlight when seedlings are young (Fischer 1982). However, walnut also suffers from competition with many faster growing species when growing in high light conditions, especially on poor sites. Also, mature stands usually contain only scattered walnut trees, so the seed source for natural regeneration is often poor. Natural walnut regeneration is thus very unpredictable, requiring just the right combination of seed source, moderate-sized canopy gaps, and sufficiently rich sites.

Advance-Growth-Dependent Species of Extreme Shade Tolerance

Sugar Maple, Beech, Hemlock

Two of the Appalachian hardwood species--sugar maple and beech--and one important conifer associate--hemlock--are tolerant enough to become established and survive for considerable periods beneath intact overstories. They achieve this by different mechanisms. Overstory sugar maples are good seed producers, with heavy crops occurring at 2- to 5-year intervals (Fowells 1965), and the large seeds can become established on undisturbed leaf litter. Seedlings cannot exist indefinitely under a completely closed canopy, but new establishment is frequent enough where a seed source exists that there are generally abundant seedlings in the understory. Beech often reproduces by root suckering, sometimes producing dense understory thickets. They can persist for many years at low light levels and still respond vigorously to release.

The small seeds of hemlock require either exposed mineral soil or the moist conditions of decaying logs or stumps for germination. Hemlock is so tolerant that it can persist for decades with very little growth under low light conditions. The adequacy of seed source can be deceptive for these species because they often occur primarily in the lower crown classes of mature stands, with faster growing species in the upper canopy. Trees in

lower canopy positions are generally not vigorous enough to produce seed, so the mere presence of these species in a mature stand does not assure adequate seed production (Marquis 1979).

Advance-growth seedlings of sugar maple, beech, and hemlock can respond to release from overstory shading if they meet the 2-foot minimum height applicable to other species, but their height growth is so slow that they will be surpassed in height by many other species. They will still survive because of their great tolerance of shade, but will be relegated to the lower crown classes of the new stand. If they are to reach the overstory at heights comparable to competing intolerant and midtolerant species, they must be of sapling size or greater as advance growth, so that they have a considerable headstart on the other species (Marquis 1981; Kelty 1986).

Stump Sprouts As a Source of Reproduction

All the Appalachian hardwood species have the ability to sprout from cut stumps to some degree. The sprouting potential decreases with age, because as the stem grows in diameter, either the bark becomes too thick for the bud to break through or the pith trace that connects the bud to the main stem pith becomes broken (Smith 1986). The decline in sprouting vigor with age varies considerably among species. All species are able to produce seedling sprouts, but sugar maple, sweet birch, black walnut, and beech do not sprout vigorously from older, sawtimber-size trees. Yellow-poplar, red maple, the oaks, basswood, and black cherry are among the most prolific sprouters. These will still produce sprouts from trees of the age at which stands are generally harvested on sawlog rotations, providing an important regeneration source for these species (Wendel 1975).

Artificial Regeneration

It would be logical to use seeding or planting to attempt to increase the proportion of the most valuable species, such as black walnut, red and white oak, black cherry, and white ash, because some of these present considerable difficulty in obtaining dependable natural regeneration. The potential for direct seeding is limited, largely because losses to animal predation are very high for many of these species, and effective, safe repellents are not available. Still, direct seeding has proven successful with some species such as yellow-poplar, even without the use of repellent chemicals (Russell 1970). However, the lack of seed production and dispersal is often not the problem, or at least not the whole problem--especially with species that regenerate best as advance growth. Adequate numbers of seeds may often be present, but the principal problem with these advance-growth species lies in obtaining seedlings of sufficient size and vigor to survive overstory removal and outgrow competition in full sunlight.

Considerable problems occur with planting many of these valuable hardwood species on open sites following clearcutting, caused by their slow initial height growth compared with competing vegetation. This is most apparent with the oaks. Natural oak advance-growth seedlings need to reach 4.5 feet in height before they are considered safely established and able to respond

to release, so it should be expected that small, 1- to 2-year-old planted oaks might perform poorly in open conditions. Even naturally established seedlings of that size would have poor survival in those conditions, and they would have larger, better established root systems compared to newly planted seedlings of the same size. In field trials, planted oaks do in fact often survive poorly, or if they survive, grow very slowly in height (Johnson 1979). The problem may be that oak planting stock must be larger, older, or have a more favorable root/shoot ratio than is normally needed when planting more intolerant, pioneer species.

Even when large, vigorous planting stock is used, fairly intensive treatments may be needed to ensure survival and stimulate height growth. Control of competing vegetation appears to be the most important requirement in achieving planting success with some species such as black walnut (Krajicek 1975; Hilt 1977). Repeated treatments may often be necessary, rather than the single release that is often adequate with conifer plantations, because of the slow initial response of seedlings. The situation is made more difficult by the fact that herbaceous competition affects hardwoods more than conifers (Bowersox and McCormick 1987). However, even effective weed control often does not result in rapid growth of planted oak seedlings (Hilt 1977; Wendel 1980). The problem of stimulating the planted seedlings to outgrow competition has led to trials of underplanting seedlings beneath an existing overstory several years prior to harvesting (Johnson 1984). This may allow seedlings to develop sufficient size and vigor to respond rapidly upon release, while reducing the growth of intolerant competitors. Another innovative but expensive remedy developed by British foresters is the placement of plastic shelters around individual hardwood seedlings; these alter the microenvironment such that seedling height growth is greatly stimulated (Kelty and Kittredge 1986). These problems associated with planting Appalachian hardwoods may be less important with intolerant species such as yellow-poplar, but they will be encountered to some degree with all species that are best adapted to establishment as advance growth.

Summary

Although there are many sources of reproduction for the Appalachian hardwood species, two sources predominate; advance regeneration and stump sprouts. Therefore, it is possible to predict the regenerative potential of many species before harvesting a particular stand, based upon their occurrence either as advance-growth seedlings of sufficient size and vigor, or as overstory trees that will produce stump sprouts after cutting.

Because advance regeneration plays such an important role, it is useful to think of the various species as occurring as a progression based upon their need to develop as advance growth and their ability as advance-growth seedlings to respond to release from overstory shading. This continuum would range from progression/pioneer species to very tolerant species as follows:

1. Pioneer species that can become established in open conditions, not requiring development as advance growth at all (e.g., yellow-poplar).

2. Species that can respond to release as fairly small seedlings, or on some sites become established in open conditions (e.g. black cherry, white ash).

3. Species that rely almost entirely on developing as advance regeneration and must achieve a large seedling size to respond to release (e.g., oak species).

4. Very tolerant species that must reach sapling size or larger before release, if they are to reach the overstory of the new stand (e.g., sugar maple, hemlock).

Placing species along this progression can be helpful in organizing thoughts about species' responses to various silvicultural treatments; however, there are enough complexities in reproductive characteristics that it is important to know the details for each species and not depend too heavily upon such generalizations.

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ROLE OF STUMP SPROUTS IN REGENERATING APPALACHIAN HARDWOOD STANDS

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ABSTRACT

Stump sprouts are an important source of regeneration in Appalachian hardwood stands. Tables are presented that show sprouting frequency and the percentage of stumps that produce sprouts. Generally, sprouting from cut stumps decreases as stump size and tree age increase. Recommendations are given for increasing or decreasing the number of sprouts in newly regenerated stands.

Introduction

Stump sprouts are an important source of regeneration in Appalachian hardwoods. It is not uncommon for stump sprouts to account for half the stems in young stands (Johnson 1976; Wendel and Trimble 1968). In the past, stump sprouts may have been ignored because they were assumed to have poor stem form and a high incidence of butt rot. However, it has been shown that stump sprouts can produce sawlogs as high in quality as those from seedlings--and usually in a shorter time (Johnson and Rogers 1983). Early identification of potential problems related to quality coupled with proper thinning techniques essentially can eliminate poorly formed and high-risk stump sprouts (Johnson and Godman 1983; Stroempl 1983).

In this paper I discuss stump sprouts, i.e., sprouts originating from cut stumps of trees at least 2 inches in dbh. Seedling-sprouts, sprouts originating from trees less than 2 inches in dbh, are discussed by others in this proceedings. Root suckers are of minor importance in Appalachian hardwood stands, limited to two commercial species--beech and black locust. Beech is a minor commercial species in Appalachian hardwood stands. Black locust normally is short-lived and is valuable for local post products and fuelwood.

I also discuss the development of stump sprouts in stands up to 5 years old and offer recommendations for increasing or decreasing the number of sprouts in these stands.

Parent-Tree Characteristics That Affect Sprouting Frequency

Species

Sprouting frequency (the number of stumps that produce sprouts) has been studied for most commercially important Appalachian hardwoods (Table 1). Basswood probably is the most prolific sprouter. Black cherry and yellow-poplar also have a high sprouting frequency. Generally, more than 90 percent of the stumps of these three species can be expected to produce sprouts. White ash, red maple, and red oak also have a high sprouting frequency.

Table 1. Sprouting frequency of Appalachian hardwood tree species (from Stroempl 1983 except where noted)

Very high	High	Medium	Low
Basswood	White ash	Sugar maple	Yellow birch[a/]
Black cherry[a/]	Red maple	White oak	Sweet birch[a/]
Yellow-poplar[a/]	Red oak	White elm	
		Black oak	

a/ From Lamson, N. I., unpublished data.

Age

Sprouting frequency usually decreases as age increases, i.e., cut stumps from older trees produce fewer sprouts than those from younger trees (Johnson and Godman 1983; Stroempl 1983). However, for most species, sprouting frequency remains fairly high for stumps of cut trees up to 60 years old (Table 2). Except for basswood, sprouting frequency generally is low for cut stumps of trees over 100 years old.

Diameter

Parent-tree dbh is perhaps the best predictor of sprouting frequency. Generally, larger cut stumps are less apt to produce sprouts (Figure 1). One-third or less of cut stumps from trees more than 20 inches in dbh can be expected to produce sprouts (Table 2). Even basswood, the most prolific sprouter in Appalachian hardwood stands, averages only 57 percent sprouting frequency when parent-tree dbh averages 20 inches. For most species, sprouting frequency is at least 50 percent for trees up to 16 inches in dbh (Stroempl 1983).

Table 2.--Percentage of stumps with living sprouts, by species and parent-tree dbh (Johnson and Godman 1983)

Species	Parent-tree dbh (inches)				
	4	8	12	16	20
	percent				
Red maple	100	79	56	43	36
American basswood	100	77	66	61	57
Northern red oak					
Parent trees 50-60 years old	--	(--------93--------)			--
Parent trees 80-110 years old	57	56	52	44	32
Black oak					
Parent trees 40 years old	57	28	16	--	--
Parent trees 80 years old	52	24	12	7	4
White oak					
Parent trees 40 years old	68	41	22	--	--
Parent trees 80 years old	28	17	10	6	4

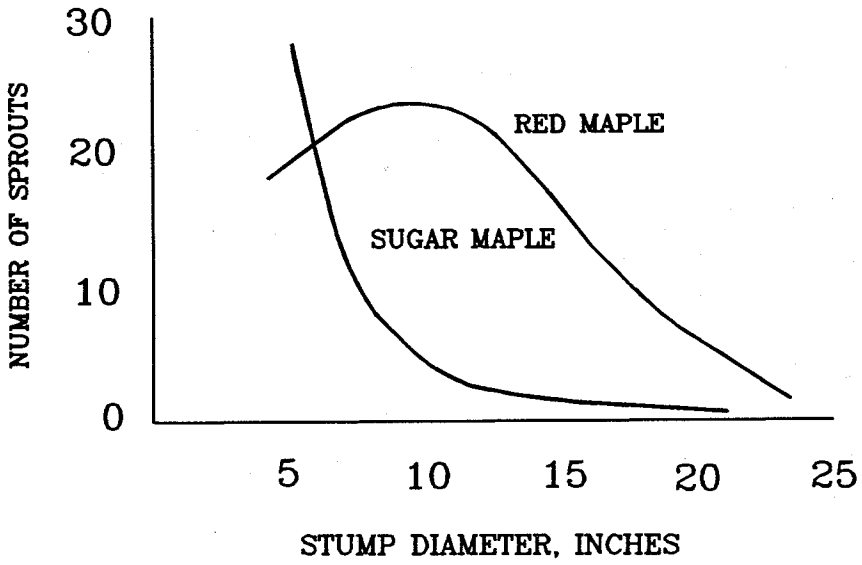

Figure 1. Relationship of number of sprouts per stump to average stump diameter (from Solomon and Blum 1967).

Other Factors That Affect Sprouting

Season of Cutting

Season of cutting has a short-term effect on the number of sprouts produced from cut stumps. During the first 5 years after cutting, most trees cut in the dormant season produce more sprouts than those cut in the growing season (Johnson and Godman 1983). However, by age 10 there is usually no difference in the number of sprouts per clump, whether trees are cut in the dormant or growing season (Wendel 1975).

Site Quality

In general, trees of similar dbh and species produce more sprouts on higher quality sites, probably because trees grow faster on higher quality sites and thus attain a size at younger ages.

Residual Stand Density

Sprouting is less frequent in thinned stands than in clearcuts. In fact, in all but extremely heavy thinnings, sprouting is of minor importance in thinned stands. Most cut stumps in thinned stands do not produce sprouts and those that do occur usually die from suppression (Johnson and Godman 1983).

Fire

The effects of fire on the sprouting of Appalachian hardwoods has not been investigated thoroughly. Burning shortly before and after clearcutting lowered the origin of sprouts to or below groundline (Hepting 1935). However, Huntley and McGee (1981) concluded that a single fire in 4- to 6-year-old upland hardwood stands does not substantially alter species composition after several years. At this time, there are no available guidelines on the use of fire to control the quantity or quality of Appalachian hardwood stump sprouts.

Butt Rot in Stump Sprouts

Decay organisms can enter stump sprouts through heartwood connections with either the decaying parent stump or dead companion stems. Decay entering from the decaying parent stump is minimal from sprouts originating at or below groundline (Roth and Hepting 1969). Current silvicultural guidelines recommend thinning sprout clumps to the best one or two low-origin, widely spaced sprouts at 5 to 10 years of age (Smith and Lamson 1986). For most species, this will largely eliminate butt rot in stump sprouts.

Red maple is a notable exception. It has been shown that decay commonly enters sprouts from poorly healed branch stubs from 4 to 12 feet above the sprout base (Tatler 1973). Therefore, red maple stump sprouts with poorly healed branch stubs should not be retained as crop stems.

Recommendations to Increase Sprouting

Land managers may want to encourage sprouting to take advantage of the rapid growth of sprouts. The following suggestions are offered.

1. Practice even-age management. Sprouts develop poorly under uneven-age management where continuous tall tree cover is maintained.

2. Shorten the rotation age to 60 to 70 years as cut stumps from younger trees produce more sprouts.

3. When thinning, retain species that produce high-quality sprouts. Retain such species as red oak, black cherry, yellow-poplar, and basswood, all of which produce high-quality sprouts.

4. Cut stumps low to encourage the development of sprouts at or below groundline. When trees with butt rot are cut, cut low stumps.

Recommendations to Decrease Sprouting

In instances where land managers may want to decrease the quantity of stump sprouts, the following suggestions are offered.

1. Practice uneven-age management to maintain a continuous forest canopy.

2. Under even-age management, use rotation lengths of at least 100 years.

3. Thin stands regularly and remove species that are the best sprouters.

4. Apply herbicides to cut stumps to prevent sprouting.

Current management guidelines for upland oaks (Dale and Hilt 1986), Allegheny hardwoods (Marquis 1986), and Appalachian hardwoods (Beck 1986) recommend two or three commercial thinnings with rotation ages from 90 to 120 years. This type of even-age management should produce fewer stump sprouts in future stands as tree size and age will be at the point that many stumps will produce few if any sprouts when cut.

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HOW VEGETATION CAN INFLUENCE REGENERATION

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Abstract

Associated vegetation can have negative or positive effects on regeneration. Plants compete with each other for light, moisture and nutrients, and they produce toxic chemicals that may interfere with a neighboring plant's ability to survive and grow. Nitrogen-fixing plants usually stimulate growth of desirable trees. A variety of plants interfere with regeneration of desirable Appalachian hardwoods. These include ferns, grasses, beech, striped maple, rhododendron, mountain laurel, grapevines, oriental bittersweet, and tolerant understories containing red maple, sourwood, dogwood, sassafras, and black gum. The evidence for interference of these plants with Appalachian hardwood regeneration is addressed in the paper.

Introduction

Foresters have recognized for many years that the vegetation present on a site can have a large effect on the regeneration process. When two or more plants occupy the same space, they interact with each other in an effort to obtain the light, water, and nutrient resources needed to survive and grow. The net effect of these interactions may be either positive or negative for the desired plant, depending upon the supply of these resources at the site and the nature of the interaction. It is important to understand how different species of forest vegetation interact with one another because these interactions have a profound effect on the species composition of vegetation, on the growth and productivity of desired species and on the rate at which succession proceeds.

Vegetation management requires information on:

1. Which species interact with the species we want to regenerate.

2. How undesirable species regenerate.

3. How they interfere with desirable plants.

4. How they may be controlled.

This paper briefly reviews the ways plants are known to interact with each other and gives information about particular species of plants that have been reported to interfere with regeneration of Appalachian hardwoods. Information on vegetation control measures is presented by Zedaker (this proceedings).

Modes of Interaction Among Plants

When the desired plant species fails to germinate, grows more slowly, or does not survive in the presence of another species (often called a "weed" species) we say that the weed interferes with the desired plant. Two categories of interference have been recognized, competition and allelopathy. Competition is the phenomenon in which one plant removes a limited resource from the environment thus restricting the growth of a neighboring plant. Shading, or competition for light, is probably the most easily observed and widely known form of competition. When the foliage of one plant is imposed above another plant, the shade light transmitted by the foliage is altered in two distinct ways. It is reduced in quantity in the visible region (400 to 700 nm) and its quality or color is changed. In particular, shade light is poorer in red and blue wavelengths and richer in far-red wave lengths. Both reduced light quantity and light with a high amount of far-red compared to red wavelengths have important species-specific effects on plant food production and on processes that effect the food allocation, size, and growth rates of different plant organs. Thus, shading effects not only plant food production, but also the plant's ability to use this food in growth.

Availability of soil moisture is another factor controlling plant survival and growth. Competition for available soil moisture by weeds can limit the growth of desirable species. Leaf expansion seems to be particularly sensitive to reduction in water supply. Due to the strong relationship between leaf area, photosynthesis, and dry weight production, a small reduction in water supply can have a large effect on growth.

Mineral nutrition has effects on all areas of plant growth. Thus, nutrients utilized by weeds can cause dramatic reductions in the growth of desired species. Nitrogen and phosphorous are the two nutrients most frequently limiting on Appalachian hardwood forest sites and these elements have been studied most often.

The second kind of interference among plants is allelopathy. Allelopathy is the phenomenon in which one plant produces and releases into the environment a natural chemical product that subsequently interferes with the survival or growth of a neighboring plant (Rice 1984). Interference between the toxic chemical in black walnut and agricultural crop plants or trees is probably the best known example of allelopathy. Toxic natural chemicals, or allelochemicals, have been found in all plant parts, but leaves and roots are the most common sources. Allelochemicals are released from plant tissue in at least four ways:

1. Leaching by rainwater.

2. Root exudation.

3. Volatilization, particularly in hot dry weather.

4. Decomposition of plant residues.

Most of these chemicals eventually get into the soil, where all or a portion of them may be fixed or broken down by soil microorganisms. Under certain conditions, allelochemicals accumulate in soil and may have an effect on the growth of a desired plant species. Thus far, there appear to be at least four broad ways that allelopathic interference may occur (Horsley 1977c). First, allelochemicals may interfere with the uptake of water or nutrients from the soil or the use of environmental resources in plant metabolism. Second, allelochemicals may interfere with changes in nitrogen from one form to another. Conversion of nitrogen from atmospheric N_2 to forms usable by plants is primarily a biological process and therefore subject to chemical interference. Third, allelopathic chemicals may interfere with the development or function of mycorrhizal relationships. And fourth, allelochemicals may interfere with plant growth by stimulating soil organisms that cause plant disease.

Interactions between plants are not always negative. The net result of an association between two plant species may be stimulation of the desired species. For example, in some intensively cultured stands, black locust, autumn-olive, and European alder have been interplanted with black walnut to take advantage of the nitrogen fixing capability of the legumes (Schlesinger and Williams 1984). Ground covers of vetch and clover have been used to provide nitrogen for planted sycamore (Haines et al 1978).

Plants Reported to Interact with Appalachian Hardwood Regeneration

A variety of plants have been reported to interfere with regeneration of desirable Appalachian hardwoods. These include ferns, grasses, beech, striped maple, rhododendron, mountain laurel, grapevines, oriental bittersweet, and tolerant woody understories containing sourwood, red maple, dogwood, sassafras, and blackgum. Evidence for interference varies greatly among species. In general, we know very little about how weeds interfere with regeneration of desirable trees. The following summaries underscore the need for increased awareness of how plants interact with each other.

Interference by Ferns

Hayscented and New York Fern

Dense fern ground covers have been associated with reduced seedling survival and growth and with regeneration failure in both northern hardwood and oak types. Hayscented fern occurs as a dense, nearly pure ground cover on thousands of acres of northern hardwood and oak forest land in New York, Pennsylvania, and the northern mountain section of West Virginia (Bowersox and McCormick 1987; Drew unpublished; Horsley 1977b, 1983, 1984a; Clay Smith, USDA Forest Service, personal communication). New York fern has a similar range, and dense ground covers have been reported in the Allegheny Plateau region of Pennsylvania and the northern mountain section of West Virginia (Horsley 1977b; Kirkham and Carvell 1980).

Both hayscented and New York fern spread aggressively following partial cuttings, such as thinnings or shelterwood cuttings. Sexual reproduction from spores occurs where bare mineral soil is present on windthrow mounds or skid trails, but their primary mode of spread is from a perennial underground stem or rhizome (Horsley 1984b). Fronds are borne on the rhizome and grow above the ground in the spring of the year. The ferns spread by repeated forking and extension of the rhizome. In partially cut stands, the rhizome not only grows faster and forks more frequently than in uncut stands, but also forms many new rhizome buds on the frond petiole. These buds grow out rapidly, greatly expanding the area covered by the fern plant. In Pennsylvania, fern spread is enhanced by an overly large population of white-tailed deer, because deer remove many other plants that would otherwise compete for space with the ferns. Since the ferns are low in deer food preference and tolerant of understory shade, they tend to expand in the understory.

Both hayscented and New York fern interfere strongly with the establishment of desirable species of regeneration in partially cut northern hardwood stands. This was shown in a study where fencing and weeding treatments were

used to distinguish the relative impacts of ferns and deer on northern hardwood regeneration after a shelterwood seed cut and after a shelterwood removal cut (Horsley and Marquis 1983). Five years after the shelterwood seed cut, there were 109,000 black cherry, red maple, and sugar maple seedlings per acre where deer had been excluded by fencing and ferns had been removed by hand weeding. There were only 20,000 seedlings per acre where seedlings were fenced, but left unweeded or where there was no fencing or weeding, an 80 percent reduction in seedling numbers. Seedlings under fern cover survive only for a short time. The same study revealed that fern also reduced the growth of black cherry seedlings after a shelterwood removal cut and that desirable species of regeneration rarely grow through fern cover. Fern cover did not interfere with the development of all species. Seedlings of pin cherry, yellow birch, black birch, and Rubus spp. grew through the fern cover and seemed not to be affected by it.

Hayscented fern also interferes with the survival and growth of planted seedlings in partially cut oak stands (Bowersox and McCormick 1987; unpublished). Survival of northern red oak, white ash, and yellow poplar was 24 to 46 percent less 4 years after planting in dense fern cover than on adjacent plots that were maintained weed-free. White pine seedling survival was unaffected by the fern cover. After 4 years, total height of surviving hardwood seedlings was 44 to 61 percent less in fern cover. Surviving white pine were 31 percent shorter in fern cover.

Studies to determine how hayscented fern interferences with black cherry seedlings in shelterwood-cut Allegheny hardwood stands suggest that interference is not through direct allelopathic effects, competitive removal of soil moisture, or interference with the development of mycorrhizal relationships (Horsley 1986). Hayscented fern does have dramatic effects on the quantity and quality of available light and on soil nitrogen. The importance of these two factors is a current topic of research. Also, it apparently contains an allelochemical natural product(s), although it is ineffective under the soil-site conditions in Allegheny hardwood stands (Horsley, unpublished). Hayscented fern foliage leachings strongly reduced growth of red maple when seedlings were grown in sand with added fertilizer solutions; no growth reduction was evident where red maple seedlings were grown in soil removed from a fern-free Allegheny hardwood stand. Presumably, soil organic matter, soil fine material or active soil microorganisms inactivated the toxin, so that red maple seedlings were uneffected.

Bracken Fern

Bracken fern is a weed of forests and pastures almost worldwide. In the Appalachians, it is a common understory plant in oak forests and it sometimes forms dense, nearly pure ground covers in old forest openings on the Allegheny Plateau in northwestern Pennsylvania. Like hayscented and New York fern, bracken regenerates primarily from an underground rhizome.

Bracken fern was one of four ground cover species associated with regeneration failure in old forest openings in Pennsylvania's Allegheny hardwood forest. Black cherry seedlings survived poorly and did not grow above the fern cover (Horsley 1977a). Studies of the mechanism of interference between bracken and black cherry suggested that an allelochemical from bracken foliage interfered with seed germination and seedling growth after seed food reserves were exhausted. In a greenhouse study, leachings of bracken fern fronds reduced shoot height and shoot dry weight 70 to 75 percent, compared with seedlings not treated with fern frond leachings. Bracken root washings had no effect on black cherry growth. The allelopathic nature of bracken fern is supported by work with a variety of herbaceous and woody plants outside the Appalachian region (Gliessman 1976; Gliessman and Muller 1978; Stewart 1975).

Sensitive and Interrupted Fern

Two other ferns of the Appalachian region have been reported to interfere with regeneration or growth of northern red oak, although neither has been reported to form dense ground covers over large areas in the region. In Wisconsin, survival and growth of northern red oak seedlings was significantly less under a dense ground cover of sensitive fern than under a cover of woody shrubs (Scholz 1955). Interrupted fern also forms dense ground cover in oak forests of the upper Mississippi River Valley. Greenhouse studies of the effect of fern frond leachings on northern red oak suggested that an allelochemical reduced seedling survival and root growth (Hanson and Dixon 1985). Seedlings began to die when seed food reserves were exhausted. Inoculation with the ectomycorrhizal fungus, Suillus luteus, resulted in better survival than for uninoculated seedlings (Hanson and Dixon 1987). Lateral roots of fern-treated seedlings had elevated amounts of chromium, a potentially toxic heavy metal, compared with seedlings not given fern leachings. Mycorrhizal seedlings had lower root chromium contents, commensurate with their higher survival.

Conclusions About Ferns

Ferns have received more intensive study than any other plant group in the Appalachian region. Ferns having rhizome systems, such as hayscented, New York, and bracken fern, tend to be aggressive invaders of partially cut or open forest sites, where they form dense ground covers. Dense ground cover of any fern should be regarded as a potential source of interference with hardwood regeneration, particularly if large acreages are involved. Overbrowsing by white-tailed deer is an important factor influencing fern ground cover development. In the Allegheny hardwood type, guidelines have been developed to determine when ferns are likely to interfere to such an extent that steps should be taken to remove it. (Marquis et al 1984; this proceedings).

Interference by Grasses

Grasses are constituents of the ground cover and the forest floor seed bank throughout the Appalachian hardwood region and have sometimes been reported to interfere with regeneration. Short husk grass occurs in nearly pure stands over large acreages in the understory of Allegheny hardwood stands in northwestern Pennsylvania. It reproduces from an underground rhizome, but also is a prolific seeder, producing large seed crops annually. A survey of regeneration in partially cut Allegheny hardwood stands showed that there were 50 percent fewer black cherry and red maple seedlings growing in short husk grass cover than a few feet away where there was no ground cover and these seedlings were 40 percent shorter than seedlings growing without grass cover (Horsley 1977b). Five years after a shelterwood removal cut, 23 percent of the black cherry seedlings growing in short husk grass survived compared with 42 percent survival where grass had been removed by hand weeding. Seedling growth in grass was 83 percent less than that on weeded control plots. Thus, short husk grass had a substantial effect on survival and growth of desirable regeneration. Unlike fern cover, if the seedlings are protected from deer browsing, grass cover does permit some seedlings to survive and grow through it.

At least part of the interference from short husk grass appears to be allelopathic. Foliage leachings reduced height growth and shoot dry weight of black cherry seedlings by about 40 percent, compared with seedlings that did not receive foliage leachings.

Wild oat grass is one of four dominant herbaceous plants that interfere with black cherry regeneration in old forest openings on Pennsylvania's Allegheny Plateau. Regeneration of this grass is solely by seed. In forest openings, mature plants produce large seed crops annually. Greenhouse studies of wild oat grass foliage leachings showed that black cherry seed germination and growth on seed food reserves were unaffected by this grass. Seedling height growth and dry weight after seed food reserves were exhausted were reduced about 40 percent compared with seedlings that did not receive foliage leachings. Wild oat grass root washings in contrast with foliage leachings, had no effect on black cherry growth. Thus, allelopathy seems to play a role in interference between wild oat grass and black cherry.

Interference by poverty oat grass has been investigated in partially cut oak stands in Pennsylvania (Bowersox and McCormick 1987, unpublished). Like its close relative, wild oat grass, poverty oat grass reproduces solely from seed. Survival of northern red oak, white ash, and yellow-poplar planted in poverty oat grass was 27 to 44 percent less after 4 years than for seedlings planted on adjacent plots that were maintained grass-free. White pine seedling survival was unaffected by the grass cover. Height growth of the

hardwoods was 35 to 50 percent less after 4 years on grass-covered plots than on grass-free plots. White pine planted in grass grew 29 percent less. Kentucky blue grass also has been reported to interfere with survival and growth of natural northern red oak regeneration (Scholz 1955; 1960).

Forest operations, such as skidding and other activities associated with logging, may have a significant effect on the amount of grass ground cover. The forest floor of most Allegheny hardwood stands contains a seed bank of grasses and sedges. Seeds of some species, such as wild oat grass and poverty oat grass, probably remain viable in the forest floor for many years (Horsley 1986; Livingston and Allessio 1968). These seeds are stimulated to germinate by logging disturbance of the forest floor. Where a large proportion of the forest floor is disturbed, a significant part of the stand may be revegetated by grass before regeneration becomes established. The amount of grass cover on the ground at the time of logging may not be a good indicator that a potential problem exists. Stands with grass ground covers as low as 1 percent sometime develop dense ground covers in disturbed areas after logging. Observation of previously disturbed areas in the stand can provide information concerning a potential problem. Where grass ground cover already exists, guidelines for evaluating whether to take remedial action are available for Allegheny hardwood stands (Marquis et al. 1984; Marquis, this proceedings). As with the ferns, overbrowsing by deer is an important factor determining whether grass ground cover develops. South of Pennsylvania, where deer browsing is not a serious problem, grass is not likely to form a dense ground cover.

Interference by Striped Maple and Beech

Striped maple and beech are common understory trees in the northern hardwood forests of the northern Appalachian region. When large numbers of these trees are present in the understory before cutting, they frequently become the dominant vegetation after cutting, excluding more desirable species of regeneration (Horsley and Bjorkbom 1983; Marquis et al 1975; Tierson 1969). Striped maple reproduces primarily from seed, although small numbers of plants originate from layering and vegetative sprouting (Hibbs 1979). In uncut stands, striped maple often is found as small 2- to 4- leaved plants that may remain suppressed in the understory for many years (Hibbs et al 1980). Growth is strongly controlled by light (Wilson and Fischer 1977). Where light is increased by partial cutting, striped maple grows rapidly and may reach heights of more than 20 feet in the understory.

Beech is one of the most shade-tolerant species in the northern hardwood forest (Hamilton 1955). Stands that contain large numbers of beech in the overstory often develop a beech understory (Barrett et al 1962). While beech reproduces from seed, most troublesome understory stems originate as suckers on the roots of overstory trees. Old beech trees often develop a

thicket of root suckers around the parent stem; sucker formation also is induced by root injury. Beech root suckers develop slowly in the understory, but when stands containing large numbers of 1 to 6 inch trees are clearcut, the crowns of these understory trees quickly close and exclude development of other species (Tierson et al 1966; Kelty and Nyland 1981). The advance of beech bark disease with its resultant mortality of overstory beech stems is likely to result in an increase in beech root suckering in northern hardwood forests of the Appalachian region, as has been the case in New England (Ostrofsky and McCormack 1986).

There usually is little desirable regeneration in northern Appalachian stands with dense understories of striped maple or beech due to overbrowsing by deer. Even small stems of these species can be troublesome in partially cut stands because they often develop faster than the less tolerant regeneration of desirable species (Rushmore 1965). Although studies of the mechanism of striped maple or beech interference have not been conducted, the dense shade cast by these species has been suggested as an important contributor to interference with regeneration establishment and growth (Hamilton 1955; Tierson 1969). Guidelines are available for evaluating whether to take remedial action to remove understory striped maple or beech in Allegheny hardwood stands (Marquis et al 1984; this proceedings).

Interference by Rhododendron and Mountain Laurel

Rhododendron and mountain laurel occur as dense understories on literally millions of acres of oak and mixed hardwood forest land in the Appalachian Mountain region. Acreage estimates vary from 3 to 6.2 million with the largest numbers of acres in the southern Appalachians (McGee and Smith 1967; Monk et al 1985; Wahlenberg and Doolittle 1950). Rhododendron occupies both moist and dry sites, but prefers moist protected sites and makes its best development there (Whittaker 1956). In the northern Appalachians, it occurs as an isolated colony in bogs or along streams (Robinette 1974b). In the southern Appalachians, rhododendron typically forms dense thickets over large acreages on moist, unexposed sites (Monk et al 1985).

Rhododendron regenerates both sexually and asexually. It has small seeds that are disseminated a short distance by wind, but its preference for short moss seedbeds or moist mineral soil restricts seedling reproduction to relatively small areas (Robinette, 1974b; Romancier 1971). Rhododendron seedlings are seldom found on the deep litter seedbeds beneath a rhododendron canopy, although seedlings that do become established may persist for 5 to 10 years. Rhododendron shoots are sensitive to fire and grazing. However, damaged stems produce vigorous root collar sprouts and root suckers (Phillips and Murdy 1985; Yawney 1962). Layering is also an important means of asexual reproduction (Monk et al 1985).

Mountain laurel is found over approximately the same range as rhododendron in the Appalachians, although the two species only occasionally are found in mixture (Hooper 1969). Mountain laurel usually occupies drier, exposed sites (Monk et al 1985). Like rhododendron, the small, dust-like seeds have exacting seedbed requirements, preferring moss or moist mineral soil (O'Keefe et al 1982; Robinette 1974a). The seedlings are moderately shade-tolerant. Asexual sprouts from the root collar or roots and layering are more frequent than seedling reproduction.

Both rhododendron and mountain laurel form thickets that are so dense that reproduction of oaks is nearly completely excluded (O'Keefe et al 1982; Romancier 1971; Wahlenberg and Doolittle 1950; Yawney 1962). More than 7,000 stems per acre have been measured in southern Appalachian thickets (Neary et al 1985). The evergreen leaves cause a dramatic reduction in light intensity at ground level. Phillips and Murdy (1985) recently quantified the effect of low density and high density rhododendron understories on regeneration of mixed oak and chestnut oak stands at the Coweeta Hydrologic Laboratory in North Carolina. They used differences in sapling density of permanent inventory plots measured in 1934 to 1935 and 1969 to 1972 to evaluate regeneration of chestnut oak, white oak, scarlet oak, black oak, red maple, and hemlock. Overstory and understory characteristics were similar on both high and low rhododendron plots. Total sapling basal area decreased on all plots between 1934 to 1935 and 1969 to 1972. However, there were significantly fewer chestnut oak and white oak stems on high rhododendron plots than on low rhododendron plots. Red maple was unaffected by the presence of rhododendron. Scarlet oak and black oak, which require disturbed seedbeds, did not regenerate well anywhere. Hemlock regenerated better under high rhododendron than under low rhododendron, probably due to its tolerance of very low light levels. Thus, rhododendron understories seem to be responsible for a major shift in species composition away from oak and toward red maple and hemlock. Also, where logging destroys the rhododendron cover and a yellow-poplar seed supply is present, these seeds germinate and the intolerant yellow-poplar grows rapidly above the thicket.

Most authors have assumed that competitive interference with light was the key factor controlling regeneration in rhododendron and laurel thickets. This is a reasonable assumption, although other alternatives have not been evaluated. Studies with sheep laurel suggest a role for allelopathy (Mallik 1987).

Interference by Grapevines and Oriental Bittersweet

Wild grapevines and oriental bittersweet cause damage and death to trees in Appalachian hardwood forests. Summer grape and its common variety, silverleaf grape, are found as far north as southern New Hampshire, although they are not common in the northern part of their range (Shutts 1974). In

the central Appalachians, they occur over a range of soil and site conditions, but prefer moist sites. Abundance of grapevines is related to site quality of important timber species, such as oaks (Trimble and Tryon 1979). As oak site quality increases, so do the number of grapevines. The vines are intolerant of shade and do not thrive in uncut or partially cut stands.

Grapevines reproduce both sexually and asexually. The seeds are long lived and store in the forest floor seedbank for at least 11 years (Wendel 1981). The vines sprout prolifically when cut and they layer easily.

Grapevines are a problem because they cause physical damage or death to desirable forest trees. Damage usually does not begin until the trees reach large sapling or small pole size (Trimble and Tryon 1979). The climbing vines break tops and branches, twist and bend stems, and uproot trees. In cases where the vines spread over the crowns of trees, the trees may eventually be killed. The geographic extent of the grapevine problem has not been reported. Most reports of damage have been from West Virginia, but grapevines also are common elsewhere in the Appalachians (Smith 1984; Trimble and Tryon 1979). No quantitative estimates of stand quality reduction due to grapevines have been made.

Interference between grapevines and affected trees appears to be primarily physical. In grape arbors where grapevines cover the crowns of trees, shading is probably an important cause of tree mortality.

Oriental bittersweet damages or kills trees in a similar way (McNab 1987). The vine was introduced into the United States from Asia in 1860 as an ornamental. Lacking pests, it naturalized quickly. By 1900, it was naturalized in Maryland, Pennsylvania, and Massachusetts, and by 1970, it could be found in 19 eastern states. Oriental bittersweet reproduces primarily from seeds. The vine is a prolific seeder and its seeds are spread easily in the excrement of birds. Unlike grapevines, the seedlings of oriental bittersweet are very shade tolerant, but the plants are capable of rapid growth and spread under partial or full light.

Shading of tree foliage seems to be the primary mode or oriental bittersweet interference. Although not currently a problem over large areas, the aggressiveness of this forest weed suggests that it warrants further study.

Interference by Tolerant Hardwood Understories in Oak Stands

The oaks are difficult to regenerate throughout their range in the eastern United States. The key factor in obtaining regeneration is the presence of abundant large (>4.5 ft.) advance regeneration and/or small oak trees that sprout vigorously when cut (Loftis 1983). Tolerant hardwood understories of sourwood, dogwood, red maple, sassafras, and blackgum play an important role in determining whether oaks are able to grow into the large regeneration

stage or reach a dominant crown position after cutting in central and southern Appalachian hardwood stands (Trimble 1973).

Soil moisture is a determinant of site quality in these stands. High quality sites are found in moist, protected coves or on mid to lower, north-facing slopes. Low quality sites are found on hot, dry south-facing aspects and ridgetops. While red maple and dogwood are found on sites of any quality, sourwood, sassafras, and blackgum are typically found on moderate or low quality sites.

All four species originate from seed in closed stands and grow slowly in the understory. All sprout readily from cut stems or the root collar. Dogwood and sassafras produce root suckers, too. Red maple and sourwood are particularly aggressive, producing large numbers of fast growing sprouts (Kays 1985).

Tolerant understory interference is most severe on high quality sites. In closed stands, the tolerant hardwoods grow slowly, forming a dense understory. When these stands are partially cut or clearcut, the tolerant species and fast-growing intolerant species originating from seed expand rapidly, overtopping the slower growing oaks, relegating them to the understory. On low quality sites tolerant understories often are less dense, thus more oak seedlings and sprouts are able to grow to large size and compete with the tolerant species.

Most authors have assumed that shading was the cause of interference between tolerant hardwoods and oaks (Loftis 1983; Trimble 1973). Although this is a reasonable assumption, the mode of interference has not been studied experimentally. Gant and Clebsch (1975) suggested that sassafras had allelopathic properties. They demonstrated the presence of several toxic chemicals in the leaves, litter, roots, and soil beneath sassafras trees and showed that these compounds reduced the germination and growth of several associated herbaceous and woody plants. Oaks were not among the species they investigated.

Conclusions

A number of herbaceous ground cover plants, woody understory shrubs, and trees interfere with establishment and development of desirable species of reproduction in the northern hardwood and oak forests of the Appalachian region. Only a few of these plants have been studied in detail. An increased research effort is needed to determine which plant species interfere with desirable regeneration, how they regenerate themselves, how they interfere with desirable regeneration and how they can be controlled. This effort will yield the practical benefit of increased ability to control the species composition and growth of Appalachian hardwood regeneration.

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EFFECTS OF FIRE ON NATURAL REGENERATION IN THE APPALACHIAN MOUNTAINS

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ABSTRACT

Research indicates that prescribed fire may have more potential in regenerating Appalachian hardwoods than demonstrated by current use. Studies show that repeated low-intensity fires increase oak advance regeneration, suggesting that a series of burns prior to harvest could result in a predominantly oak stand. Single pre- or post-harvest burns have little affect on species composition of the advance regeneration. Following harvest, winter burns on cove sites have stimulated the establishment of yellow-poplar from seed stored in the duff. Summer broadcast burns, used in conjunction with the proper time to fell residuals and planting, are currently used successfully to regenerate mixed pine-hardwood stands. Recent studies indicate that prescribed fire can be used in the steep terrain of the Appalachians with minimal adverse environmental effects if properly conducted. More research is needed to completely document the role that fire might play in regenerating Appalachian hardwoods and the effects that increased use of fire may have on the environment.

Introduction

Probably less is known concerning fire effects in the Eastern hardwood forests than in any other timber type. This statement is not meant to imply that fire has had a small ecological role in this region. Ecologists have long recognized that upland oak stands in pre-Colonial America depended upon recurring wildfires for their continued existence (Cooper 1961). Other species, like yellow-poplar, developed adaptations that enabled them to successfully regenerate on fire-prepared seedbeds.

Prescribed fire is seldom used as a forest management tool in the Appalachians. However, some research indicates that it may have potential benefits when cautiously used in certain forest cover types of the region. More research is needed before specific recommendations for its use can be made.

The purpose of this paper is to discuss the current state of knowledge concerning effects of fire on natural hardwood regeneration in the Appalachian Mountains and to briefly review environmental effects of prescribed fire in steep terrain. Since relatively little information is available concerning fire in this region, sources dealing with studies beyond the Appalachian boundaries will be cited where necessary.

Effects of Fire on Hardwoods

Most of the information concerning effects of fire on hardwoods has come from studies of hardwood control in pine stands of the Coastal Plain and Piedmont. These studies have shown that the size, but not the number, of understory hardwoods is controlled by fire. Low-intensity prescribed burns are effective in top-killing most hardwood stems up to a 3-inch ground diameter (Langdon 1981). However, root stocks of top-killed hardwoods will generally produce multiple sprouts.

Hardwood sprouting after top-kill by frequent fires is extremely persistent, although the ability to continually resprout varies by species. Oaks tend to be the most resistant to mortality from periodic fires. Frequent burning (annual or biennial) increases herbaceous vegetation. Therefore, various combinations of fire frequency and timing can affect the composition and structure of understory vegetation, including the advance regeneration pool of hardwood stems.

Forty years of understory burning on the Santee fire plots in the Coastal Plain of South Carolina illustrate the effects of prescribed fire on the hardwood understory in mature loblolly pine stands (Waldrop et al. 1987). Understory growth was vigorous and composed of all size classes of hardwoods up to 20 in dbh on control plots which had received no burning for 80 years. On plots burned periodically (about every 5 years), the great majority of hardwood stems are less than 1 inch dbh. The only hardwood stems greater than 6 inches after 40 years of burning were those that were large enough to survive the early fires. These periodic fires were frequent enough to top-kill most of the hardwood stems less than 2 inches dbh, but their root systems survived and produced multiple sprouts. Burns of 5 year intervals were evidently not frequent enough to promote oak regeneration. All species survived, but oaks decreased in abundance, possibly due to shading from shrubs and other understory vegetation.

Annual winter burning of the Santee fire plots produced the largest numbers of stems less than 1 inch dbh, but nearly all of these stems were less than 3 feet tall. These cool dormant season burns caused little mortality of hardwood root stocks. Sprouting of oaks was increased over controls, but the gain was masked by a seven-fold increase in the number of sweetgum sprouts.

Biennial summer burning produced the most positive response in terms of promoting oak advance regeneration. Growing season burns were of sufficient intensity to kill hardwood root stocks. After a period of 6 to 8 years (4 to 5 biennial burns) the relative abundance of oaks began to increase because of their superior resistance to mortality from fire. After 14 biennial summer burns, oak survival was over 50 percent as compared to less than 20 percent for other hardwoods.

Only annual summer burning was capable of complete elimination of understory hardwoods. Burning in the summer top-kills small hardwoods when most of the carbohydrate reserves are in the tops of the plants and sprouting vigor is low. A series of annual summer burns gradually killed the root stocks of all understory hardwoods, including the oaks.

Types of Prescribed Fires

Prescribed fires are generally of one of three types. Head fires burn with the wind or upslope. They are of relatively high intensity and move through fuels at a relatively high rate of speed. Head fires are often ignited in strips (called strip headfires) to speed the burning process and to provide the desired intensity. Fire intensity increases as the rear of a previously ignited strip merges with the advancing front of a subsequent strip.

Back fires back into the wind or burn down slope. They burn with lower flame heights, i.e., lower intensity, and move through the stand at slower speeds than head fires. Back fires, because of their lower intensity and slower speeds, are more easily controlled.

Flank fires are sometimes used to supplement other burning techniques. They are often used to speed the process of burning with backfires. Flank fires are set perpendicular to backfires. Where flank fires merge, fire intensity increases.

Fire Intensity, Residence Time, and Fire Severity

Fireline intensity is defined as the heat output of a unit length of fire front per unit of time (Deeming et al. 1977). Fireline intensity is directly related to flame length, a readily observable feature of a fire. It is important in prescribed burning because intensity is a major factor determining mortality or damage to both understory and overstory hardwoods. As trees grow larger they become more resistant to fire because their crowns are above the heat of the flames and thicker bark provides greater insulation to the cambium. Thus, hotter fires are necessary to kill or damage larger trees.

In addition to fire intensity, the duration of exposure or residence time is an important consideration when planning a prescribed fire. Protoplasm can be instantly killed at a temperature of 147° F, but also can be killed by

prolonged exposures to lower temperatures (Nelson 1952). Backing fires of low intensity can be lethal to small stems because their slow speeds enable lethal cambium temperatures to be reached just above the ground line. Conversely, where understory stems are larger and have thicker bark, headfires are likely to be more lethal than backfires because of damage to the crowns.

It is important to appreciate the difference between fire intensity and severity. Fire severity is defined as the condition of the ground surface after the burn (Wells et al. 1979). Fire intensity relates to the rate at which an on-going fire is producing thermal energy. The two terms are not necessarily closely related, although they may be. For example, a burn that consumes all the organic layer and alters mineral soil structure and color over most of the burned area would be classified as a severe burn. A high intensity fire in heavy fuels that burns when the soil and forest floor are moist would leave a large amount of residual forest floor and not alter soil structure and color. Thus, in this example, a high intensity fire would be classified as light severity.

Environmental Effects of Fire in the Appalachians

By necessity, we will confine our remarks concerning fire effects on the environment to the Southern Appalachians and upper Piedmont. Effects of burning on the soil vary. High intensity wildfires burning under droughty conditions may expose the soil to erosion and cause heat damage to soil physical properties (Wells et al. 1979). Conversely, intense broadcast burns in the Southern Appalachians under proper fuel and soil moisture conditions do not necessarily result in increased erosion or reduced infiltration rates (Van Lear and Danielovich 1988). To minimize soil damage and off-site effects of broadcast burns in steep terrain, it is extremely important to conduct the burns so that a residual forest floor will be left to protect the site. To accomplish this, the lower portion of the forest floor and the mineral soil must be damp.

Low intensity burns normally consume only a portion of the forest floor and have little impact on soil properties or water quality. Brender and Cooper (1968) found no evidence of soil movement after a single prescribed fire in the Piedmont of Georgia. Douglass and Van Lear (1983) noted that two low-intensity understory burns in mature loblolly pine plantations had no adverse effect on ephemeral stream sediment or nutrient concentrations in the South Carolina Piedmont. Adverse impacts on soil and water from infrequent low intensity burns are not generally detected because of the protective effect of the residual forest floor and because hydrologic functioning and soil processes are maintained at normal levels. Research is needed to evaluate the effects of high intensity fires on nutrient pools and biological processes in these mountain ecosystems.

There are few long-term studies of effects of prescribed burning on soil chemical properties in the Southern Appalachians. On the Highland Rim in eastern Tennessee, Thor and Nichols (1974) found no significant effect of annual or periodic winter burning over a 7-year period on soil pH or available phosphorus. Available potassium tended to be higher in unburned stands, perhaps because potassium, a highly mobile element, may have been leached or taken up by vegetation more readily on burned plots. On the Coastal Plain, other long-term burning studies have shown that low-intensity prescribed fires have little adverse impact on soil fertility and may improve such properties as available phosphorus and organic matter content (McKee 1982).

In the southeastern United States, prescribed burning is often used to improve habitat for game and non-game species. Reports which summarize these numerous studies were given by Harlow and Van Lear (1981, 1987). Increased sprouting of hardwoods and other browse after burning has been commonly reported. The protein and phosphorus content of browse, as well as palatability, are improved following burning (Stransky and Harlow 1981), but these improvements are short lived. Fruit production of understory plants, such as gallberry, huckleberry, and blueberry, may be reduced if burning cycles are less than 3 years (Stransky and Halls 1980).

The effect of prescribed fire on wildlife depends on the particular species of wildlife, fire frequency, fire intensity, season, and fuel types. Interrelationships among these factors are complex. In addition, habitat requirements for some wildlife species are not well defined. For these reasons, it is often difficult to predict effects of prescribed fire on wildlife in general. Programs of burning that favor certain species may create conditions unfavorable to others. A close working relationship between foresters and wildlife managers, both of whom must understand fire effects, is necessary to design fire prescriptions that will benefit those wildlife species favored in management.

Air pollution must be a major concern when a prescribed burning program is considered. Smoke is rapidly dispersed high into the atmosphere and causes few problems when burning is conducted under appropriate atmospheric conditions. However, when smoke settles on highways or impacts other sensitive areas, accidents and lawsuits may result. Besides its effects on visibility, smoke contains several compounds known to affect human health (McMahon 1985). Smoke management guidelines have been developed to reduce the atmospheric impacts of prescribed fire (USDA Forest Service 1976). Smoke management will be a major concern if fire is used more frequently in the Appalachians, where topography and population distribution dictate that smoke be effectively dispersed.

Burning to Enhance Natural Regeneration

Research on the use of fire for hardwood regeneration is limited, which is partially due to foresters' concern of damaging stem quality in high value stands. However, much of the information on bole damage comes from early studies of wildfires (Abell 1932; Nelson et al. 1933), which may not be applicable to lower intensity prescribed fires. Sanders et al. (1987) found that low intensity backing fires in mature hardwood stands during the winter had little adverse effect on crop trees.

The potential for damage to boles of thin-barked hardwoods by high intensity fires is readily evident from the numerous fire scars seen in many Appalachian stands. However, the role of low-intensity prescribed fires in stand management and the use of higher intensity broadcast burning for promoting quality coppice regeneration deserves greater attention from fire research. Researchers are now beginning to realize that hardwood species evolved under a regime of frequent burning and that prescribed fire may be a useful tool in hardwood management (Van Lear and Waldrop 1987). At present, research results on the use of fire for hardwood regeneration are limited to the oak-hickory, cove hardwood, and pine-hardwood cover types.

Oak - Hickory Cover Type

The oak-hickory type is widespread in the eastern United States, covering over 114 million acres of commercial forest land (Burns 1983). However, regeneration of this type has been difficult. Today it is recognized that even-aged management of oak types is necessary and that regeneration can be accomplished by similar techniques to those used for other intolerant types (McGee 1975). Clearcutting and shelterwood cutting are acceptable regeneration techniques but advance regeneration of oaks is required to compete with other species in the understory (Roach and Gingrich 1968). Sufficient quantities of adequately sized advance oak regeneration to comprise a major component of the regenerated stand are often difficult to obtain. Sander (1972) suggests that a minimum of 435 oak stems per acre over 4.5 feet tall is required for successful regeneration. One theory, yet to be proven, for the failure to successfully regenerate oak stands is that the exclusion of fire or other disturbances has altered the ecology of these stands to the detriment of advance oak regeneration (Van Lear and Johnson 1983).

Some research lends support to this theory. Two studies conducted in the Northeast (Swan 1970; Niering et al. 1970) and one in the southern Coastal Plain (Langdon 1981) found that seedlings of oaks are less susceptible to root kill by fire than competitors of other species, thus giving the oaks an ecological advantage. This fact would indicate that periodic burning can play a major role in promoting advance oak regeneration. Waldrop et al. (1987) reported that survival of oaks was greater than for competing species after 4 to 5 biennial summer burns. Periodic (2 or more years) fires may be

the key to oaks predominating over their associates. However, the exact combination of season and frequency of burning to promote advance oak regeneration in the Appalachians has not been determined.

Several studies support the theory that multiple prescribed burns are necessary to promote advance oak regeneration prior to harvest. Thor and Nichols (1974) found that advance regeneration of oaks in central Tennessee was doubled by both annual (for 6 years) and periodic (2 burns, 5 years apart) prescribed fires. Carvell and Tryon (1961) reported large increases in advanced oak regeneration in West Virginia where stands had been burned several times over a 20 year period. Keetch (1944) found that oak sprouting was stimulated by a single prescribed fire and was maintained by three successive fires.

A single fire has little effect on species composition in the understory and may provide conditions more favorable for light-seeded species and those which depend on seed stored in the forest floor (Loftis 1978). Johnson (1974) reported that a spring fire in a 102-year-old northern red oak stand failed to increase oak abundance in the understory. The fire also failed to control competing vegetation and killed 58 percent of the existing seedlings. Wendel and Smith (1986) reported no increase of advance oak regeneration after a single spring burn in a central Appalachian oak-hickory stand. The fire caused severe damage to the boles of overstory trees and increased competing vegetation. Teuke and Van Lear (1982) found only slight benefits to oak regeneration after single winter burns in western South Carolina and northeastern Georgia.

Two studies have reported effects of post-harvest prescribed burns on oak regeneration. McGee (1979) noted little change in species composition after a single burn in 5- to 6-year-old stands on the Cumberland Plateau in northern Alabama. Sprouting of red maple was increased, so the relative dominance of oaks decreased. Waldrop et al. (1985) used a spring burn in a 3-year-old hardwood stand on the Cumberland Plateau in East Tennessee. Burning caused little change in species composition. Both burned and unburned plots were dominated by oaks but oak abundance did not increase relative to other species.

With both studies of post-harvest burning, only a single burn was attempted. If the resistance of oaks to root-kill that was demonstrated on the Santee Fire Plots (Waldrop et al. 1987) holds true for oaks in the Appalachians, several periodic prescribed burns may have resulted in increased oak abundance. Repeated post-harvest burns offer the advantage of maintaining browse for deer over a number of years, but their effects on oak regeneration have not been studied.

With any prescribed burning operation, the potential for success must be considered before making the decision to risk the use of fire. When the objective of burning is to increase oak sprouting, a large portion of the understory must be oaks that are small enough to be top-killed by fire.

Hardwoods over 3 inches dbh generally survive low-intensity prescribed fires. In many older and undisturbed stands, smaller oak stems have been shaded out of the understory. In this case, burning may not be beneficial or should be postponed until after a shelterwood cut allows oak seedlings to become better established.

Cove Hardwoods

The task of regenerating oaks, particularly northern red oak, is more difficult on cove sites than on upland sites. On moist and fertile cove sites, understory vegetation competes vigorously with oak seedlings and usually overtops them. Therefore, advance regeneration of desired species is required. In addition, some control of the subcanopy and midstory is necessary to favor advance regeneration (Loftis 1980).

Recent publications suggest that fire exclusion from cove sites has created environmental conditions unsuitable to oak regeneration (McGee 1979; Russell 1979). However, research on the use of periodic fire for regenerating cove hardwoods is lacking. Two current studies by Loftis (1978; 1980) will provide more information on the use of fire in cove sites. One study will examine the effects of periodic fire on understory species composition, while the other will examine the effects of periodic fire and various levels of basal area removal on the development of advance oak regeneration.

While fire has not been proven to promote oak regeneration on cove sites, it has been successful for regenerating yellow-poplar. This species has adapted to fire disturbance by developing light seed which is disseminated by wind and gravity and germinates rapidly in fire prepared-seedbeds. Yellow-poplar seeds also remain viable in the duff for approximately 10 years and then germinate rapidly after a fire (McCarthy 1933). Sims (1932) found that yellow-poplar seedlings were more numerous in clearcut and unharvested stands that had been burned as compared to similar stands that had not been burned. Shearin et al. (1972) noted that the number and height of yellow-poplar seedlings were significantly increased on Piedmont sites three growing seasons after a low intensity winter burn on a clearcut area. Viable seeds stored in the duff before burning accounted for the large number of seedlings after burning.

Pine-Hardwood Mixtures

While forest management is traditionally aimed at pure pine or mixed hardwood stands, a new site preparation technique for promoting pine-hardwood mixtures is gaining widespread acceptance in the Southern Appalachians. This technique, commonly described as "fell and burn", relies heavily on the use of broadcast burning. Detailed descriptions of the fell and burn technique were given by Abercrombie and Sims (1986), Phillips and Abercrombie (1987), and Van Lear and Waldrop (1987) and are summarized here.

The fell and burn site preparation technique consists of two steps. After clearcutting hardwood or pine-hardwood stands, generally on medium quality sites, residual stems over 6 feet tall are felled by chainsaw crews. Felling is conducted during the early spring following full leaf development. Timing is critical because carbohydrate reserves in the roots are at their lowest after leaf development and resulting sprouts will be of reduced vigor. Also, the presence of leaves will speed the drying of small twigs and serve as fuel for a broadcast burn, which is the second step of the technique. Burning is conducted in mid-July to early August within 24 to 48 hours after a soaking rain, ensuring that a residual forest floor and root mat will provide protection against erosion. Improved shortleaf or loblolly pines are planted the following winter.

While this technique does not reduce the number of hardwood sprouts that compete with planted pines, it does reduce sprout vigor enough to allow pines to become established and grow (Danielovich et al. 1987). Pine survival is generally over 90 percent the first year after planting and over 75 percent after 4 years (Phillips and Abercrombie 1987). In three stands planted with shortleaf pine, oaks were numerous but much shorter than pines. Oaks were generally less than 6 feet tall while pines averaged over 8.5 feet.

Summer broadcast burning is probably the more beneficial of the two steps in this site preparation technique. Sprouts that developed after chainsaw felling are top-killed and new sprouts are less vigorous. Burning removes over 65 percent of the woody fuels less than 3 inches in diameter (Sanders and Van Lear 1987), making the site more accessible for planting. After planting, the black surface makes green seedlings more visible, thus ensuring a better job of planting. The fire also kills aboveground buds on hardwood stumps, forcing new sprouts to originate from below ground ensuring that they are better anchored and of better form.

The fell and burn technique has proven valuable in producing pine-hardwood stands in the Southern Appalachians. It is an inexpensive technique that increases diversity by adding a pine component, improves habitat for deer and turkey, and is well accepted by the general public. However, many questions remain unanswered. At present, there are no stands regenerated by this technique older than 7 years. Therefore, future growth and yield and the need for intermediate treatments is yet to be determined. Also, the fell and burn technique has not been attempted outside of the Southern Appalachians so problems specific to other areas are unknown.

Conclusions

Prescribed fire is an increasingly used forest management tool in the southern Appalachians. Studies suggest the fire could be an important tool

in regenerating hardwoods and have potential benefits when applied to certain forest cover types. Some general thoughts concerning prescribed fire and Appalachian hardwoods are:

1. Single preharvest or postharvest fires have little effect on species composition of advanced regeneration.

2. Repeat low intensity fires increase oak advanced regeneration as well as increase top-kill of most hardwood stems up to a 3-inch ground diameter.

3. Root stocks of top-killed hardwoods produce multiple sprouts.

4. Fire kills above ground buds on hardwood stumps forcing new sprouts to originate from below ground resulting in sprouts that are of better form and low-origin.

5. Frequent burnings (annual or biennal) continues to stimulate root stock sprouting of certain species such as oaks. Herbaceous vegetation increases too. Burns at 5-year intervals are not frequent enough to promote oak regeneration. Thus, periodic prescribed burns may be used to control competing vegetation and favor advanced oak regeneration.

6. During burning, it is extremely important some residual forest floor be left to protect the site. The key is moisture. The lower portion of the forest floor and mineral soil must be damp when burning is conducted.

7. High-intensity broadcast burns conducted when fuel and moisture conditions are appropriate have little effect on soil erosion and hydrology.

8. Summer broadcast burns accompanied by properly timed felling of residual trees and planting of pine seedlings are currently successful for regenerating mixed pine-hardwood stands. Burning greatly reduces logging residue, thus, helps planting and allows the planted seedlings to successfully compete with sprouts.

9. Postharvest winter burns on cove hardwood sites stimulate the establishment of yellow-poplar from seed stored in the duff. Seed germinates rapidly in the fire-prepared seedbeds.

10. Both low- and high-intensity prescribed fires can benefit several wildlife species by increasing sprouting of nutritious and palatable vegetation.

11. Burning often increases herbaceous forage and associated insect populations, a benefit to certain wildlife species.

12. Although foresters are concerned about stem quality of valuable hardwoods, evidence suggests that low-intensity fires in light fuels have little adverse effect on large trees.

13. Information is needed on how burning influences nutrient cycling and biologic processes in steep terrain.

Air pollution resulting from prescribed burning is a concern, especially in the terrain of the Appalachians. Population density may also limit the potential of this valuable management tool. The utmost care in conducting burns in accordance to smoke management guidelines is essential if burning is to become a part of forest management in Appalachian hardwoods.

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EFFECTS OF CUTTING PRACTICES ON MICROENVIRONMENT IN RELATION TO HARDWOOD REGENERATION

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ABSTRACT

Regeneration cutting results in significant changes in the microenvironment of the forest floor and soil. For example, light intensity, surface soil temperature, and soil moisture increase with removal of the forest canopy. These changes influence regeneration success directly through their impact on photosynthesis, heat and frost damage, and available soil moisture. Changes in the microenvironment also influence available nutrients because decomposition and nutrient cycling processes are strongly regulated by soil temperature and moisture. Nutrient availability is further influenced by changes in dry deposition and leaching through the logging slash. The degree of changes in the physical, chemical, and biological properties of the forest floor and soil is dependent upon cutting intensity. Thus, silvicultural prescriptions should consider the microenvironmental requirements of the desired regenerating species.

Introduction

Removal of part or all of a hardwood overstory canopy results in significant changes in the physical, chemical, and biological properties of the forest floor and soil. The establishment and growth of hardwood regeneration are regulated by these changes in the microenvironment since light, temperature, moisture, and nutrients are crucial to plant processes.

The objectives of this paper are to examine effects of different hardwood regeneration harvest methods on the microenvironment and the potential influence of changes on the establishment and development of regeneration. We prefer to use the broader term "microenvironment" instead of "microclimate" because biological and chemical processes that take place in the plants and soil are strongly linked to site conditions. Major variables

we plan to discuss are illustrated in Figure 1. Cutting alters solar radiation and hence the energy balance of the land surface. Consequently, variables such as temperature and moisture of the forest floor and soil are also altered. Changes in the physical factors produce significant changes in nutrient input, uptake, and biological processes such as decomposition and transformation of nitrogen to a form available for plant uptake. In this paper, our approach will be to discuss basic principles and suggest expected changes in the microenvironment. Emphasis will be placed on clearcutting because response information is most abundant for this harvest method.

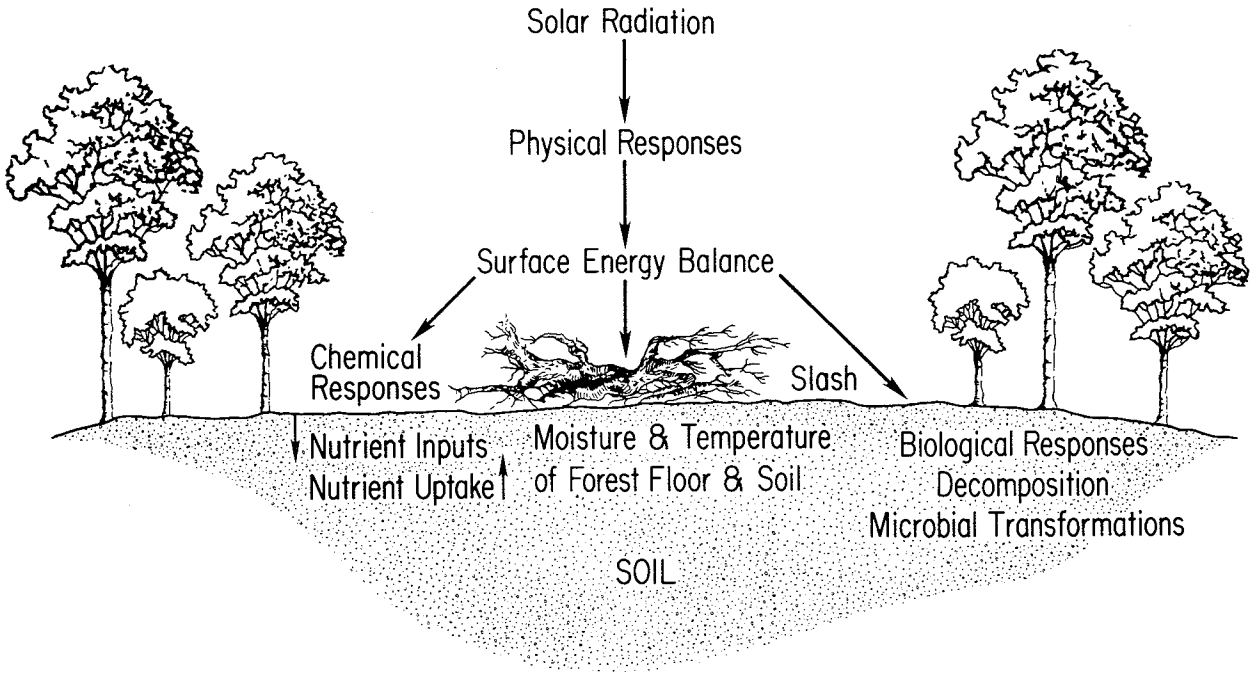

Figure 1. Illustration of major components of the microenvironment in response to regeneration cutting.

Physical Responses

Solar Radiation (Light)

Alteration of solar radiation is the largest and most important change to the microenvironment that accompanies cutting practices (Wallace 1988). Removal of even a part of the forest canopy strongly affects both the intensity and quality of light reaching the forest floor. Kramer and Kozlowski (1979) conclude that tree growth is influenced more by changes in light intensity than by changes in light quality. Generalizations about the utilization of energy (light) in the ecosystems are difficult to make. Swift (1972) found that different energy components following clearcutting of hardwoods in the Southern Appalachians were dependent upon season and topographic position. However, he concluded that clearcutting reduced energy used for plant growth, water evaporation, and heating of soil and air (daily net radiation) on both north- and south-facing slopes about 350 to 460 Watts/m^2 in the growing season.

The magnitude of change in light intensity after removal of the forest canopy depend on the amount of canopy removed or the size of the opening (Wallace 1988). In full leaf, a closed hardwood stand reduces light intensity at the forest floor to about 90 percent of the light received in open areas. However, after leaf-fall, light increases to about 50 percent of values received in the open areas. Increases in light due to regeneration practices are not proportional to the amount of canopy removed because of repeated reflection and absorption of radiation in the remaining canopy (Reifsnyder and Lull 1965). Thus, the intensity of light available to seedlings and sprouts declines rapidly from clearcutting conditions to about 35 percent crown density. Thereafter, available light decreases more slowly with increasing crown density (Kramer and Kozlowski 1979). Between 50 to 75 percent of a stand would have to be cut to increase summertime light intensity to half of that in the open (Reifsnyder and Lull 1965).

The amount and type of reproduction associated with various silviculture methods are strongly dependent upon changes in light intensity reaching the forest floor after harvest. Rates of photosynthesis (plant growth) increase in proportion to light intensity until light saturation occurs; thereafter, photosynthesis is generally constant. Maximum photosynthesis for species such as white oak, red oak, and dogwood may occur at light intensities of about one-third of full light while light saturation of red maple is much lower (Kramer and Kozlowski 1979). In mixed oak stands of West Virginia, Carvell and Tryon (1961) found that oak regeneration density increased linearly over the range of 5 to 40 percent sunlight.

The ability of species to respond to increased light intensity is not solely dependent upon maximum photosynthetic rates. For example, recent efforts have focused on photosynthesis and growth responses of seedlings to changes in available light for photosynthesis activity--400 to 700 nm wavelength

(Wallace 1978). Additionally, some species exhibit other physiological and morphological responses to increased light intensity that may allow them to grow in a variety of light conditions (Wallace 1988). Wallace and Dunn (1980) found that intermediate shade-tolerant species such as white oak, red oak, red maple, and ash had a range of physiological and morphological responses to changes in the microenvironment created by forest openings. In contrast, shade-intolerant yellow-poplar has rigid physiological and morphological characteristics that may restrict this species to sites with abundant light.

At the present time, insufficient information is available to predict changes in light intensity produced by different regeneration methods. Moreover, specific light requirements, in combination with other physiological responses for the numerous species that occupy mixed hardwood stands, is not well known. Thus, the best practical guidelines for species light requirements are probably the long-established criteria of shade tolerance (Baker 1934).

Moisture and Temperature

Due to the influence of the remaining overstory, small openings (less than about 0.2 acre) in the overstory will change the moisture and temperature characteristics of the microenvironment less than light intensity. However, with large clearcut openings, significant alterations of both moisture and temperature occur.

Examples of changes in moisture and temperature as related to clearcutting are illustrated by a long-term study at the Coweeta Hydrologic Laboratory in the Southern Appalachians. Beginning in January 1977, a 147-acre, south-facing watershed covered by mixed hardwoods was clearcut and logged with a mobile cable system. Removal of commercial sawlogs was completed in June 1977 and site preparation (clear-felling all remaining stems >1 inch) was completed in October 1977. A number of environmental responses to the clearcut treatment were compared to an adjacent undisturbed hardwood forested watershed.

Beginning in August 1977, soil moisture was measured at biweekly intervals in the O_1 and O_2 (organic) litter layers of the forest floor and approximately 0 to 4 inches and 4- to 12-inch depths in the soil of treated and control watersheds. A summary of moisture data shows how changes in light intensity and temperature at the forest floor as well as reduced evapotranspiration (combined loss of water by evaporation from the soil surface and by transpiration from plants) influence litter and soil moisture (Table 1). In the first autumn following harvest, litter moisture content was 20 to 30 percent below that of the adjacent undisturbed forest (Table 1). With winter precipitation soil recharge and reduced evaporation, litter moisture content was similar on both watersheds. During the spring, summer, and autumn periods of the ensuing year, moisture content of the O_1 and

O_2 layers of the forest floor in the clearcut area was consistently 30 to 50 percent lower than values from the undisturbed watershed.

Table 1. Quarterly forest floor and soil moisture averages (percent) for mixed hardwood forests during the first year after clearcutting (WS 7) and for a control (WS 2) at the Coweeta Hydrologic Laboratory.

Treatment and depth	Year and Quarter			
	1977		1978	
	Aug-Nov	Dec-Mar	Apr-Jul	Aug-Nov
	Moisture content (percent by weight)			
Clearcut				
O_1	70	124	88	51
O_2	95	170	97	58
0 to <4 inch	46	70	55	31
4 to 12 inches	36	40	34	23
Control				
O_1	92	121	120	105
O_2	126	211	120	109
0 to <4 inch	35	59	36	28
4 to 12 inches	32	40	29	24

O_1 = Includes fresh or slightly decomposed organic materials.

O_2 = Includes intermediate and highly decomposed organic materials.

In contrast to reduced forest floor litter moisture after cutting, soil moisture increased substantially, particularly in the A horizon (<4 inches) where most roots are concentrated. Increases of more than 11 percent were observed during the first full year after clearcutting, while moisture values deeper in the soil profile (4 to 12 inches) were increased 4 to 5 percent above values from the undisturbed site (Table 1).

With rapid sprouting and growth of regeneration observed in the Southern Appalachians, the moisture regime of the forest floor and soil returns close to precutting levels in 3 to 5 years on some sites. However, the large, initial changes of moisture in the forest floor and surface soil incurred using clearcutting-type practices have important implications for germination, sprouting, and early growth of various hardwood species.

Regeneration methods such as light selection cutting, which remove only a small portion of the stand, have no significant effect on soil moisture. For example, watershed studies in the Appalachians (Douglass and Swank 1975) have shown that at least 25 percent of the overstory basal area in mixed hardwood stands must be cut to obtain measurable changes in streamflow due to reduced evapotranspiration. Even in large openings produced by some group selection cuttings, roots of trees located around the edge of the opening effectively compete with regeneration for the extra soil water produced by cutting.

Clearcutting also changes soil temperatures. In the previously described commercial clearcut at Coweeta, soil temperature at the litter-soil layer was measured during the precut year (1976) and in subsequent years after logging. Monthly data for the period May through October show that in the first growing season after clearcutting the mean monthly temperature of the surface was 15^{o} to 20^{o} F above precut levels (Figure 2) and reached a maximum of 85^{o} F in July and August. Mean monthly maximum temperatures showed large increases with soil temperature being 10^{o} to 50^{o} F above precut levels. The mean monthly maximum temperature was 120^{o} F or above in August through October (Figure 2) and daily maximum temperatures frequently exceeded 130^{o} F during this period. In subsequent years, increases in surface soil temperature were moderated by shade from reproduction but even after 6 years of regrowth the mean monthly maximum temperature exceeded 100^{o} F late in the growing season.

The magnitude and timing of altered surface soil temperatures have important consequences for the establishment, survival, and growth of hardwood reproduction. Exposure of plants to high temperatures can cause direct or indirect heat injury. The temperatures where active plant cells die varies from 120^{o} to 140^{o} F and depends on species, age of tissue, and length of exposure to high temperature. Temperatures in excess of 140^{o} F produce injury due to the breakdown of proteins. Indirect effects of high temperatures include growth reductions due to reduced photosynthesis and depletion of carbohydrate reserves, disruption of plant cell tissues, and loss of moisture from high transpiration rates.

Low temperatures may also cause injury or mortality to hardwood reproduction by freezing above-ground plant tissue and roots, causing frost rings, frost cracks, and winter sunscald lesions. Species specific requirements and/or tolerances with respect to high and low temperatures are probably better documented for conifers than for hardwoods.

Nutrients and Biological Activity

Another primary response of regeneration practices is the alteration of nutrient cycling and biological processes. Direct effects include reductions in plant uptake and atmospheric deposition of nutrients. Indirect effects include changes in biological activity that regulate nutrient availability through decomposition (microbial breakdown of organic

matter) and transforation of nitrogen (N) by microorganisms to a form that is utilized by plants.

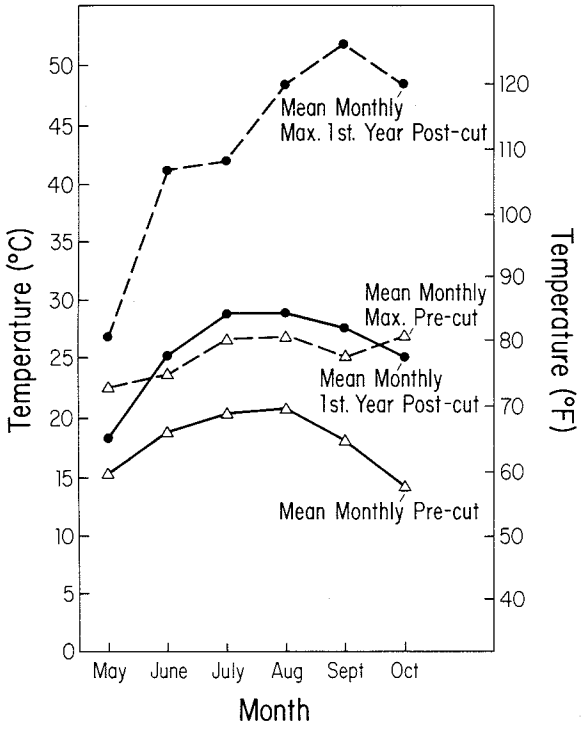

Figure 2. Mean monthly and mean monthly maximum temperatures measured at the litter-soil interface on Coweeta WS 7 prior to clearcutting and the first growing season after cutting and logging.

Direct Responses

The most immediate change in forest nutrient cycles associated with regeneration cuttings is the temporary reduction or elimination of plant nutrient uptake. The increased pool of soil nutrients can follow several pathways including loss from the soil by leaching, immobilization by soil microorganisms, gaseous losses, adsorption to soil exchange sites, or uptake by the remaining trees and/or other vegetation.

With light cuttings, increased nutrients will be primarily utilized by the residual stand rather than the reproduction. At the other extreme, clearcutting provides a substantial increase in available soil nutrients that are utilized by sprouts and seedlings. The utilization of nutrients after clearcutting by early successional species has been documented at Coweeta and is due to both high nutrient concentrations in plant tissue and rapid growth rates (Boring et al. 1988).

Atmosphere. The atmosphere is a significant source of plant nutrients, such as nitrogen, that partially replenishes losses from timber harvesting (Swank 1984). Nitrogen is deposited to a forest canopy in several forms as both wet and dry deposition. The dry form is comprised of small particles containing nitrate (NO_3), ammonium (NH_4), and gases such as nitric acid vapor (HNO_3), nitric oxide (NO), and nitrogen dioxide (NO_2). These dry forms require a three dimensional reaction surface such as a forest stand in order for deposition to occur. Recent studies in mixed deciduous forests (Lovett and Lindberg 1984; Kelly and Meagher 1986) have estimated that nearly 60 percent (7 pounds per acre per year) of the total deposition of N to the forest occurs in the dry form.

Clearcutting temporarily eliminates the forest canopy surface and thus reduces the dry deposition N inputs. Light selection cuts probably have sufficient canopy surface to capture most forms of dry N deposition. The importance of dry deposition to nutrient input varies by element and geographic region.

Slash. Another direct effect of regeneration cutting on the nutrient cycle involves the availability of nutrients in residual slash remaining on site. The long-term release of nutrients associated with decomposition is discussed later, but an important component involves changes in the nutrient composition of precipitation as it passes through ("throughfall") logging slash.

Studies were conducted for the commercial clearcut at Coweeta where precipitation and throughfall were collected for chemical analysis. In the first growing season after cutting there was a general increase of nutrients in throughfall water as the water moved through the slash to the forest floor (Table 2). Calcium (Ca), phosphate (PO_4), and potassium (K) concentrations increased 14-fold, 14-fold, and 3-fold, respectively, over ambient precipitation concentrations, while elemental nitrogen as nitrate (NO_3-N) was immobilized in slash and showed a 3-fold reduction in concentration. Thus large amounts of certain nutrients were mobilized and readily available for sprouts and seedlings.

In contrast to clearcutting, light selection cutting would produce only small amounts of slash with patchy distribution. Thus, increases in nutrient input to the forest floor via throughfall would be minor.

Indirect Responses

Decomposition. Following forest harvesting practices, large amounts of logging slash typically remain on site. The amount, distribution, and composition of the logging slash are functions of the silvicultural harvest system used, removal techniques, and utilization intensity.

Table 2. Comparison of select nutrient concentrations in bulk precipitation and slash throughfall for the period April-August 1978 during the first growing season after clearcutting (Coweeta WS7).

Hydrologic compartment	Mean nutrient concentrations			
	NO_3-N	PO_4	K	Ca
	----------Parts per million--------			
Precipitation	.24	.03	.21	.43
Slash throughfall	.08	.42	3.10	1.47

From a practical standpoint, logging slash may physically inhibit natural regeneration, make planting difficult, and increase fire hazard to the regenerating stand. From a biological standpoint, the input and subsequent decomposition of large amounts of organic matter (i.e., roots, leaves, woody debris) has a dramatic influence on carbon and nutrient cycling processes in hardwood forests. These processes provide the nutrients required for successful regeneration and growth.

Rates of organic matter (OM) decomposition following forest removal are primarily functions of changes in microenvironment, the chemical composition of the OM, and the size and type of the OM constituents (i.e., leaves, branches, stemwood).

As previously discussed, soil temperature and moisture have been shown to increase the first year following forest removal. Changes in microenvironment may stimulate or inhibit decomposition processes, depending upon the soil temperature and moisture optimums of the decomposing organisms. In the Southern Appalachians at Coweeta, decomposer activity was reduced in the first postcut year on a south-facing watershed, coincidental with decreases in populations of decomposing organisms (Waide et al. 1988; Seastedt and Crossley 1981). As summarized earlier, soil temperatures on this site often exceeded 120° F during summer months in the first postcut year. As the canopy recovered and soil temperature moderated, decomposer activity increased to near preharvest levels. In contrast, the altered microenvironment following forest removal in cooler climates may stimulate decomposer activity and subsequent OM decomposition rates (Bormann and Likens 1979). Additionally, partial overstory removal has less impact on microenvironmental parameters than does total overstory removal. Thus, changes in decomposition processes following shelterwood or selection cutting would generally be lower than those associated with clearcutting.

Decomposition rates are also determined by the chemical composition of the organic matter. Decomposing organisms utilize the carbon in OM as an energy source, but they also utilize nutrients such as nitrogen (N) to decompose the OM. Thus, factors such as the carbon:nitrogen (C:N) ratio of the OM are often highly correlated with decomposition rate. Other factors related to composition of OM such as the lignin content or lignin:nitrogen (L:N) ratio also appear to regulate OM decomposition (White et al. in press). In general, the lower the C:N or L:N ratio, the faster the decomposition rate. Thus, decomposition rates vary among species, and by tissue type within a given species, because the chemical composition of OM is quite variable. For example, Mattson et al. (1987) found a more than 10-fold difference in decomposition rates of logging slash of 17 tree species. Within a species, tissue decomposition rates generally follow a pattern of fine roots > fresh leaves > old leaves > twigs > branches > stemwood. Differences between tissue type are related to both tissue quality and surface area/mass relationships.

Microbial Transformations. Most research on the impact of forest removal on microbial transformations has been concerned with the N cycle because (1) N most commonly limits tree growth, and (2) concern over the effects of increased mineral N on stream and ground water quality. Thus, our discussion will focus on the effects of forest removal on several important microbial processes in the N cycle such as:

1. N mineralization--conversion of N from the organic to inorganic form (ammonium)--available to plants.

2. N immobilization--conversion of N from the inorganic to organic form--not available to plants.

3. N nitrification--conversion of ammonium to nitrate--highly available to plants, but subject to leaching losses.

4. N fixation--conversion of gaseous nitrogen to a plant-useable form.

5. Denitrification--reduction of nitrate to gaseous N or N oxides--not available to plants.

N mineralization is the microbial process whereby ammonium (NH_4^+) is released from OM as it decomposes. The impacts of forest removal on N mineralization processes are related to the effects of forest removal on microenvironment and the quality and quantity of the logging slash and organic matter. For example, at the Hubbard Brook Experimental Forest in the northeast, N mineralization increased substantially following forest overstory removal, resulting in a net N loss from the soil of 421 pounds per acre over a 3-year period (Bormann and Likens 1979). In contrast, only modest increases in total N mineralization (9 to 27 pounds per acre per year) were observed on a clearcut watershed in the Southern Appalachians

(Waide et al. 1988). However, in the Hubbard Brook clearcut, no products were removed and regeneration was prevented with herbicides. Thus, factors related to the quantity of the logging slash and organic matter, improved microenvironment for decomposition, and inhibited N uptake by early successional species probably contributed to the high soil N losses at Hubbard Brook.

Mineralization rates also depend upon the quality of the logging slash. In general, slash with low C:N ratios, such as fresh foliage and twigs, mineralizes faster than slash with high C:N ratios, such as branches and stemwood (Mattson et al. 1987). Additionally, many pioneer species have high N concentrations and low lignin contents resulting in increased N mineralization following forest removal (Vitousek 1981).

The availability of mineralized N for seedling uptake and/or ground and stream water losses depends, for the most part, on immobilization and nitrification processes. Nitrogen is immobilized in the decomposition of material with high (>25:1) C:N ratios (Vitousek 1981). Eventually, decomposition reduces the C:N ratio of the logging slash-organic matter and mineralization occurs. The immobilization of ammonium (NH_4^+) by soil microorganisms can be a very important nutrient conservation mechanisms in clearcut forests (Aber and Melillo 1982); however, immobilization makes less NH_4^+ N available for seedling uptake. Because of its positive charge, NH_4^+ can also be adsorbed on negatively charged soil particles. As a result, NH_4^+ losses in ground and stream water are relatively unimportant. However, through the microbial process of nitrification, NH_4^+ is converted into the highly mobile nitrate (NO_3^-) anion. Because of its high mobility, NO_3^- is believed to be more available for seedling uptake than NH_4^+, but NO_3^- is also subject to leaching losses. Forest removal can increase nitrification rates, probably through a combination of changes in microenvironment and increased NH_4^+ availability (Robertson 1982). For example at Coweeta, nitrification increased 3-fold to 15-fold following clearcutting (Waide et al. 1988). This response was paralleled by a 10-fold to 20-fold increase in nitrifying bacteria. Similar results have been shown in a clearcut forest at Hubbard Brook (Likens et al. 1968).

Nitrogen may be increased in clearcut forests by a variety of plant species and N fixation bacteria existing together. Symbiotic associations (Frankia, Rhizobium) in roots of early successional tree species such as black locust can result in increased N inputs of 9 pounds N per acre per year or more (Boring and Swank 1984). Clearcutting can also increase bacterial N fixation. For example, at Coweeta, clearcutting increased bacterial N fixation by 8-fold in the 0- to <4-inch soil layer and by 4-fold in the 4- to 12-inch soil layer (Waide et al. 1988).

Denitrification occurs when anaerobic microorganisms reduce NO_3^- to produce N_2 and N_2O gases. Gaseous losses of soil N to the atmosphere reduces N available to plants. Unfortunately, gaseous N losses via denitrification have proven very difficult to quantify. Initial estimates of denitrification losses at Coweeta were on the order of 4.5 to 10 pounds N

per acre per year for control and clearcut watersheds, respectively (Waide et al. 1988). However, recent detailed studies by Davidson and Swank (1986) suggest that these earlier estimates were too high. Instead, losses on the order of <1.0 pound N per acre per year or less are probably more realistic. Small increases in denitrification might occur following clearcutting because of increased NO_3^- and higher soil moisture. However, methodological difficulties prevent accurate determination of the importance of this process in either undisturbed or clearcut forests.

Summary and Conclusions

Successful regeneration of hardwood seedlings or sprouts depends upon the availability of favorable microenvironmental conditions required for growth and survival. Removal of the forest canopy alters several key physical and biological factors.

Key points concerning physical factors (light, moisture, temperature) of the microenvironment include:

1. Intensity of light available to seedlings and sprouts declines rapidly from clearcutting to about 35 percent crown density. As crown density increases above 35 percent, the available light decreases more slowly.

2. Amount and type of reproduction associated with various silviculture methods are strongly dependent on changes in light intensity reaching the forest floor after harvest.

3. Maximum photosynthesis for species such as white oak, red oak, and dogwood may occur at light intensities about one-third of full light, while red maple is much lower.

4. Presently, information is not available for predicting changes in light intensity produced by different regeneration methods. Thus, the shade tolerance criteria developed by Baker (1934), are probably the best practical guidelines for species light requirements.

5. Large initial changes in moisture in the forest floor and surface soil as a result of using clearcutting-type practices have important implications for germination, sprouting, and early growth of various hardwood species.

6. With rapid sprouting and growth of regeneration observed in the southern Appalachians, the moisture regime of the forest floor and soil returns close to precutting levels in 3 to 5 years on some sites.

7. Regeneration methods such as single-tree selection, which remove only a small portion of the stand, have no significant effect on soil moisture.

8. Soil temperature increases greatly following clearcutting. In southeastern forests, soil temperatures may exceed 120° F.

9. High temperatures result in lower growth rates caused by reduced photosynthesis and depletion of carbohydrate reserves, moisture stress, and production of lesions or breaks in plant cell tissue.

Key points concerning forest nutrient cycles are:

1. The most immediate change in forest nutrient cycles associated with regeneration cutting practices is the temporary reduction or elimination of plant nutrient uptake.

2. With light cuts, increased nutrients are primarily utilized by the residual stand rather than the reproduction. Clearcut areas provide a substantial increase in available soil nutrients that are utilized by sprouts and seedlings.

3. Clearcutting temporarily eliminates the forest canopy and this reduces the dry deposition nitrogen inputs.
Light selection cuts probably have sufficient canopy surface to capture most forms of dry deposition.

4. Due to abundant slash and the general increase of nutrients in rainfall as it moves through the slash to the forest floor, clearcut areas provide large amounts of certain nutrients (calcium, phosphorus, potassium) that are readily available for sprouts and seedling stems.

5. In forests in the northeast, removing the forest canopy may stimulate decomposition of the organic matter; however, in forests in the southeast, decomposition may be reduced.

6. Partial overstory canopy removal has less impact on the microenvironment than complete canopy removal. Thus, changes in decomposition of the organic matter following shelterwood or selection cutting practices would generally be lower than those associated with clearcutting.

7. Decomposition of slash is quite variable among species. A 10-fold difference has been observed among 17 tree species. Within a species, decomposition follows the general descending pattern that fine roots decompose faster than fresh leaves, old leaves, twigs, and branches. Bolewood decomposes at the slowest rate.

8. Impacts of forest cutting on nitrogen mineralization and nitrification processes (conversion of N to forms useable by plants) are related to the effects of forest removal on microenvironment and the quality and quantity of the logging slash and organic matter. Both processes usually increase with forest cutting.

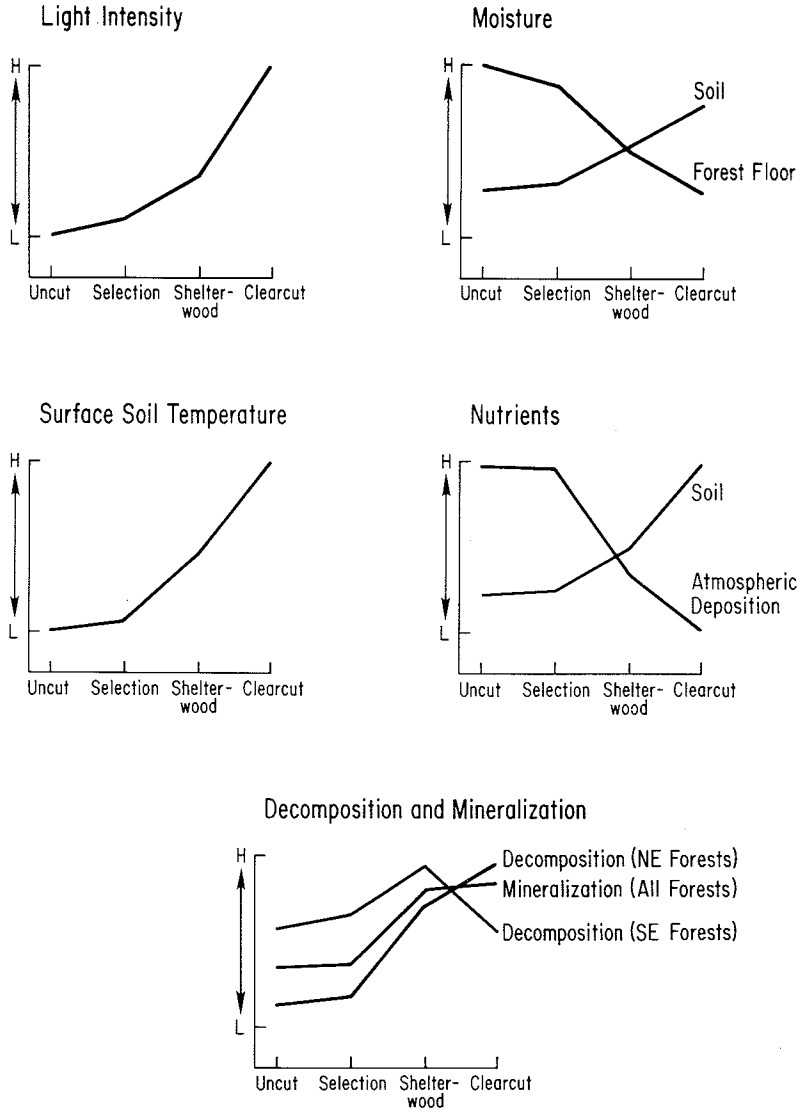

Figure 3. A summary of how different regeneration cutting practices may affect the status of microenvironmental factors with reference to uncut forests. The harvest methods shown on the horizontal axis are intended to represent a continuous range of forest harvest. The factors on the vertical axis range from low (L) to high (H).

An attempt to synthesize the key points in relation to regeneration methods is illustrated in Figure 3. The vertical scale indicates the relative level of each environmental variable over a range of forest canopy densities. In many cases, rankings represent hypotheses since quantitative data are lacking. The response patterns indicate that the regenerating seedling is influenced by several environmental factors which ultimately determine its growth and survival. Ideally, silvicultural prescriptions should account for the microenvironmental requirements of the desired regenerating species. Unfortunately, our knowledge of environmental limitations to hardwood seedling growth and survival, particularly with regard to silvicultural treatment, is quite limited. As emphasized in a recent document of research priorities for eastern hardwoods (McLintock 1987), growth and survival. Ideally, silvicultural prescriptions should account for the microenvironmental requirements of the desired regenerating species. Unfortunately, our knowledge of environmental limitations to hardwood seedling growth and survival, particularly with regard to silvicultural treatment, is quite limited. As emphasized in a recent document of research priorities for eastern hardwoods (McLintock 1987), the highest priority must be given to programs that build upon ecological studies that examine the "how" and the "why" of cause-effect relationships. The need for a more comprehensive understanding of species requirements, interactions with environmental factors, and the specific mechanics of stand treatment effects on forest structure and development were also emphasized. This knowledge can only be gained through interdisciplinary research of silviculturalists, plant physiologists, forest meteorologists, and forest ecologists.

Acknowledgements

This research was supported in part by the Southeastern Forest Experiment Station and in part by NSF Grant DEB 77-05324. The authors thank J. B. Waide and L. W. Swift, Jr., for their helpful reviews of the manuscript and for information supplied in some of the analyses.

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EFFECTS OF WHITE-TAILED DEER ON APPALACHIAN HARDWOOD REGENERATION

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ABSTRACT

The purpose of this paper is to examine the magnitude of the white-tailed deer problem as it relates to regeneration in Appalachian hardwood stands. Deer numbers and Appalachian hardwood forests have always been interrelated. Deer are dependent on hardwood browse and hardwood regeneration is dependent on deer browsing. White-tailed deer can significantly alter the composition of Appalachian hardwood forests through their browsing. Browsing can affect stand regeneration by reducing seedling numbers, reducing seedling height, altering species composition, delaying stand establishment, or causing complete regeneration failure. Deer in the southern Appalachians consume less browse than do deer in northern Appalachians, and impacts of deer on stand regeneration are much more significant in the northern Appalachians. Economic losses due to deer reducing regeneration are unknown, but they probably exceed $10.00 per acre per year for the northern Appalachians. Positive impacts of deer are limited, being restricted to the reduction of competition by browsing trees commercially less desirable. White-tailed deer populations in the Appalachians are increasing at an unprecedented rate and the impacts on hardwood forests are potentially disastrous.

Introduction

Appalachian hardwood forests and the white-tailed deer which populate them have always been dependent upon each other. Historically, climax forests supported relatively low densities of deer, except at those times when natural disasters such as fire and windstorms occurred. These natural events opened up the forest canopy and permitted sunlight to reach the forest floor. This resulted in a rapid growth of both herbaceous and woody plants which was followed by an increase in deer numbers.

A wide-spread increase in forest openings occurred when settlers cleared the land. Extensive lumbering followed settlement and resulted in a significant increase in browse production. Although extensive slash fires often delayed forest succession and the production of deer browse plants for several years, forest regeneration was inevitable.

Deer populations did not immediately respond to this superabundance of food because of wide-spread overhunting. It was not until the middle of the 1900's that deer populations began their unprecedented explosion which has not yet slowed. Over-protection of does, a lack of large predators (especially mountain lions), and almost unlimited food were responsible for the greatest density of white-tailed deer which has ever occurred in the Appalachian Mountains.

Deer numbers have historically been determined by forest structure, but future forest structure may be determined by deer numbers. White-tailed deer can significantly alter the composition of a forest through their browsing of sprouts and seedlings. At the extreme end of the scale, deer can completely eliminate all forest regeneration. At lower deer densities and light browsing pressure, they can modify forest composition by selectively browsing certain preferred tree species. The purpose of this paper is to examine the magnitude of the deer problem as it relates to regeneration in Appalachian hardwood stands.

Deer Food Habits

Deer feed on a wide variety of plant materials, including both herbaceous and woody. Grasses, forbs, fruits, nuts, leaves, and twigs are all commonly eaten by deer. Almost every hardwood species is eaten. Maples, oaks, black cherry, and birch are commonly listed as preferred deer foods, while hickories, sourwood, and beech are of low preference. It is impossible to generalize in more detail because of the variation in preference between states and seasons-of-year.

Deer consume woody browse at all seasons of the year, but species preference varies from season to season. For example, in central Pennsylvania red maple was browsed heavily only in winter, while white ash and yellow birch were browsed mainly in summer, and yellow-poplar and cucumber were browsed equally heavy in all seasons (Bramble and Goddard 1953).

Healy (1971) wrote that deer in northwest Pennsylvania browsed most heavily in winter (49 percent of feeding time). Harlow and Hooper (1971) found that deer in the southern Appalachians consumed more twigs in spring (55 percent occurrence in rumen) than in other seasons. Twigs comprised 41 percent of the diet in winter, 38 percent in summer, and 37 percent in fall. Cushwa et al. (1970) noted that in the southeastern Appalachians virtually all browsing of twigs took place in spring and summer seasons when plants are growing rapidly and twigs are most succulent. Ruff (1938), as cited by Cushwa et al. 1970, found that deer in North Carolina consumed more twigs in spring and summer than in winter. Twigs accounted for only 5 percent of the

total volume of food consumed in winter, whereas succulent twigs accounted for 40 percent by volume of foods eaten in spring and summer.

Deer in the southern Appalachians consume less browse than deer in the northern Appalachians. Wentworth et al. (1987) reported that woody twigs made up less than 5 percent of winter diet of deer in the southern Appalachians. Cushwa, et al. (1970) concluded that in southeastern Appalachians, hardened twigs made up less than 1 percent of deer food in fall-winter.

Shaw and Ripley (1966) noted that woody browse comprised 5.6 percent of the diet of deer in northern Appalachian forests, compared to 3.2 percent for deer in southern forests. One of the few studies to compare browse preferences between states was conducted by Stiteler and Shaw (1966) on six Appalachian National Forests. Woody twigs made up nearly 19 percent of food consumed by deer on national forests in the northeastern United States, but less than 10 percent on forests in the southeastern United States. Red maple was highly preferred in the White Mountain National Forest but was of low preference in George Washington and Jefferson National Forests.

Impacts of Deer Browsing on Individual Plants

Deer can affect a young tree in many ways. They can prevent the germination of seedlings by eating nuts or fruits of hardwood trees. However, deer are only one of many wildlife species which feed on acorns, nuts, and fruits. Any of these not eaten by deer will be gathered, or eaten by some other wildlife species (especially rodents).

Deer can directly kill trees in several ways, including: (1) pulling young seedlings from the ground, (2) repeated browsing of the seedling or sprouts, and (3) eating bark and effectively girdling the tree. Deer can also kill saplings by rubbing them with their antlers. This behavior can result in complete girdling and eventually death of the tree.

Impacts of Deer on Stand Regeneration

Although deer may kill or prevent the growth of large numbers of hardwood trees, this does not necessarily result in an adverse impact on stand regeneration. If adequate advanced stocking is present, deer may not remove enough young trees to have a significant effect. Browsing can affect stand regeneration by reducing seedling numbers, reducing seedling height, altering species composition, delaying stand establishment, or causing complete regeneration failure (Redding 1987).

Impacts of deer on stand regeneration are much more significant in the northern than in the southern Appalachians. This is directly due to the heavier browsing pressure in the north and indirectly to the greater variety of food plants (woody and herbaceous) available in the south. Shrauder (1984) wrote that deer in southern Appalachians seldom cause damage to young forest stands, probably due to greater number of stems per acre and longer growing seasons.

In North Carolina, browsing did not have a significant effect on hardwood species or composition (Moore and Johnson 1967). This occurred in an area having a deer density of greater than one deer per 10 acres. Cromer and Smith (1968) found in the Monongahela National Forest that less than 6 percent of the stems in clearcuts were browsed. They concluded that there were no significant differences in deer browsing on fenced and unfenced plots. Harlow and Downing (1970) wrote that in the southern Appalachians "... deer browsing had no significant effect on species composition or abundance." However, they did find that both seedlings and stump sprouts were taller in fenced plots than in unfenced plots. A total of 51 percent of the seedlings in fenced plots were over 4.5 feet tall, compared to 13 percent of the seedlings in unfenced areas. Also 61 percent of the sprouts in fenced plots were over 4.5 feet tall compared to 5 percent of the sprouts in unfenced plots.

Most studies that investigated deer food habits in the southern Appalachians were conducted during the 1940 to 1970 period when deer numbers were considerably lower than they are now. If these studies were repeated today, frequency of browsing and impacts on regeneration might be much higher.

The most serious impacts of deer on hardwood regeneration seem to occur in Pennsylvania and its neighboring states. More studies involving inter-relations of deer and forests have been conducted in Pennsylvania than in any other state, with most being directed by personnel from the Northeastern Forest Experiment Station.

Moderate to heavy deer browsing in Pennsylvania has resulted in nearly pure black cherry regeneration, with other hardwood species being eliminated (Tilghman 1987). Oak sprouts are a preferred deer food at all seasons and are often eliminated in areas having high deer densities. Gottschalk (1987) reported that stems of commercial species were significantly higher in fenced stands than in unfenced areas in Pennsylvania. Species composition of regenerating stands consisted of red maple and undesirable commercial species where deer numbers were high.

Several studies in Pennsylvania have shown that deer are eliminating all commercial seedling and sprouts, including black cherry. Shafer et al. (1961) found only beech seedlings in unfenced plots, compared to over 5,000 saplings of commercial hardwood species in fenced plots. Grisez (1959) found over 4,000 seedlings of commercial hardwood species inside a fenced area compared to fewer than 700 outside (including 620 gray birch). Other studies in Pennsylvania have also documented a significant reduction in hardwood stems outside exclosures, compared to those inside exclosures which were protected from browsing (Jordan 1967; Marquis and Grisez 1978). Marquis (1981) conducted regeneration surveys in 13 clearcuts in Pennsylvania and found that deer browsing resulted in inadequate stocking, delay in establishment, and less valuable species composition. Only 38 percent of unfenced areas were adequately stocked, compared to 92 percent of fenced areas.

Deer in the central Adirondacks also alter regeneration of hardwood stands. Sugar maple, yellow birch, and white ash were almost eliminated by deer in unfenced areas. In contrast, beech was more common outside exclosures than inside (Tierson et al. 1966).

Most browse studies have examined the impacts in clearcuts or heavily cutover areas. Of greater importance may be the effects of deer on regeneration in stands before cutting occurs. Browsing that eliminates understory seedlings will significantly affect regeneration success (Marquis 1978). Few exclosure studies have been initiated in forests before timber harvest occurred, thus few data are available on this aspect of deer browsing.

Economic Impacts of Deer Browsing

Few studies have assessed the economic losses due to deer reducing regeneration. Marquis (1981) estimated that the value of timber production lost following clearcutting as a result of browsing during the regeneration period averaged $1,075 per acre in Pennsylvania. Losses from deer damage were projected to average $13.00 per acre (stumpage value) per year over the Allegheny Plateau of Pennsylvania.

Tierson, et al. (1966) wrote that deer can convert a beech-birch-maple stand worth $100 to $200 per thousand board feet to a monoculture beech stand having a value of $35 per thousand.

Positive Impacts of Deer Browsing on Regeneration

No studies have documented that deer have a positive impact on hardwood regeneration. However, there are a few ways in which such a positive impact might occur. Removal of trees that are commercially less desirable would reduce competition and thus increase numbers and size of more valuable trees. Red maple is apparently more preferred than is black cherry, thus deer could favor black cherry regeneration by browsing red maple.

Deer may affect the commercial value of future stands by preferring sprouts over seedlings. Moore and Johnson (1967) found that 57 percent of sprouts were browsed compared to only 14 percent of seedlings. Seedlings, however, were four times more numerous than were sprouts. Succulent stump sprouts were browsed much more severely than were the slower-growing root sprouts. Similar findings have been reported by Cook (1946); Jordan et al. (1965); Healy (1971).

In heavy cutover areas where sprouting is profuse, heavy early browsing may be desirable because it holds sprouts in reach of deer for a much longer time. This extended browsing on sprouts of noncommercial species will also result in the release of seedlings of commercial species (Jordan 1967; Moore and Johnson 1967).

Michael (1987) reported that deer in one area of north central West Virginia stripped the bark from 56 percent of all slippery elm trees. Many trees were completely girdled and died. Deer also removed the bark from exposed roots of slippery elm trees. No other tree species had bark stripped by deer in this area. This selective girdling of a noncommercial species should result in increased growth of preferred commercial species, due to decreased competition. Bark-stripping could become a negative impact in the future if deer begin feeding on commercially valuable trees.

Deer may benefit hardwood regeneration by adding fertilizer in the form of fecal pellets. Assuming 15 pellet groups per day per deer and 20 grams per group, a deer thus deposits 110,000 grams (250 pounds) per year. At one deer per 10 acres, 25 pounds per acre per year are added to the forest soil. All 25 pounds are not active ingredients and tree growth may not be significantly affected by these available nutrients.

Conclusions

White-tailed deer populations in the Appalachians are increasing at an unprecedented rate and the impacts on hardwood forests are potentially disastrous. Hardwood forests will never be eliminated by deer, but their structure will be drastically changed due to overbrowsing. Both understory and overstory species composition will be altered and growth rates will be modified.

Deer populations cannot continue to increase at this same rate, but densities will never be lower than they are now. Appalachian hardwood forests will be changed so drastically that they will be quite different from the forests we have known in this century. Forests and foresters of the 21st century will face many problems, with one of the most serious involving white-tailed deer.

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CONTROLLING DEER PROBLEMS IN HARDWOOD STANDS

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ABSTRACT

When deer are creating problems in hardwood forest management, forest managers have several options to control the problem. These options are discussed in detail. The first option, reduction of deer numbers, involves hunting to remove some of the deer thereby reducing browsing pressure. Some advantages of lease hunting versus public hunting are also discussed. Option two, modification of deer behavior, involves establishing alternate food sources for the deer to reduce the browsing on hardwood regeneration. Protection of the regeneration is the third option. A relatively inexpensive and effective electric fence to reduce deer browsing is described along with guidelines when to use the fence.

Introduction

Finding ways to control or alleviate damage to hardwood regeneration caused by white-tailed deer can be difficult and costly. The degree of control needed varies depending on the deer population level and the abundance or lack of regeneration.

Deer control measures can be grouped into four areas, reduction of deer numbers, modification of deer behavior, protection of the regeneration and modification of forest management practices. The latter measure will be discussed in detail in other papers so this paper will deal with the first three.

Reduction of Deer Numbers

When a deer problem is occurring because the herd is too large, it is obvious the number of deer needs to be reduced. Hunting is the best way to achieve this. Opening the land for free public hunting allows deer to be harvested, does not cost the landowner anything except possibly the repairing of logging roads used by vehicles. Antlerless hunting is the key to reducing deer numbers or keeping populations stable. Buck hunting only, will in most cases allow the population size to increase. If deer problems are not too severe, allowing public hunting which includes antlerless harvests can alleviate specific deer problems.

One concern with relying on free public hunting is that the landowner has little control over the number of hunters on the land and does not know who the hunters are. Therefore, if increases or decreases in the harvest are desired it is difficult to accomplish. An alternative to free public hunting is lease hunting. This involves a group of individuals renting the exclusive hunting rights on a parcel of land. In addition to the obvious economic benefits of a lease program antlerless harvests can be larger and there is a greater ability to adjust harvest. From 1982 through 1984 Hammermill Paper Company conducted a study to compare deer harvest, success rates, etc. on lands that were open to the public and leased lands (Brenneman 1985). Over the three hunting seasons included in the study the average annual antlerless harvest on the leased area was 11.6 deer per square mile and 8.6 on the areas open to the public. During the second and third years of the study the lease group was asked to increase the antlerless harvest and the average annual antlerless harvest during 1983 and 1984 was 12.9 deer per square mile compared to 7.4 on the public areas or 43 percent higher. Leasing provides a greater flexibility to change the harvest rate, especially for antlerless deer. Most leased areas had fewer hunters than areas open to the public but success rates are usually higher for both antlered and antlerless deer. Success rates for antlerless deer on the leased area averaged 86 percent during the 3-year study and 48 percent on the public areas.

One of these areas that was open to the public during the 3-year study (1982 to 1984) was subsequently leased in 1985 and 1986. The antlerless harvest increased by an average of 36 percent after leasing. Other measures to reduce deer numbers could include live trapping and immobilization with drugs. Both of these techniques are very time consuming, expensive and mortality of the deer may be high.

Modification of Deer Behavior

In some situations it may be possible to modify deer behavior so that some of the browsing is shifted to plant species other than hardwood browse. We have observed on company land that hardwood regeneration is often more abundant in stands that are in close poximity to cultivated fields. this leads to the assumption that the deer are spending more time feeding in the fields, reducing the amount of time browsing on hardwood regeneration. In a study using radio collared deer, Brenneman (1987) found that in over 82 percent of the tracking periods near dusk, deer came into fields adjacent to the forest to feed. Devlin and Tzilkowski (1986) found that the grass was a major food item in the diet of elk and white-tailed deer in Pennsylvania during spring, summer and fall, with the highest use in spring. McCaffery and Creed (1969) also reported high use of grassy openings by deer in spring and fall.

In areas with large contiguous blocks of forested land there may be very few openings available for deer to feed on and they have no choice but to feed in the hardwood stands. Perhaps if openings, 0.25- to 1.5-acre, were strategically placed throughout a forested area they would mitigate

some of the deer damage to hardwood regeneration. The time of year when these openings are most frequently used by deer also coincides with the time of most severe hardwood browsing damage. Forage crops such as alfalfa and clover are used even more intensively than other grasses and would make these openings even more attractive to deer.

A recently established 1.0-acre opening in a forested area on company land is being used frequently by deer and turkey. It has not been established long enough, however, to see any changes in hardwood regeneration.

The distribution of the openings would play a role in determining the affect on hardwood regeneration. There is data available that indicates deer will not move long distances to feed. Taber and Dasmann (1958) stated that mule deer are sedentary on their home range and they will not leave even for an attractive new source of food. Brenneman (1987) found that even when a white-tailed deer's home range was less than one half mile from a newly established clearcut the deer did not move outside of that established home range to feed in the clearcut.

Openings established on an area to mitigate damage to hardwood regeneration would need to be distributed so that they were available within the home range of most of the deer.

Protection of the Regeneration

If deer problems cannot be alleviated through deer reductions or modification of deer behavior, protection of the regeneration is the next alternative. This can be attempted either chemically or mechanically. Chemical repellents are expensive and the need for frequent reapplications and problems with phytotoxicity during the growing season make their use impractical in most forest management situations. Recent research with systemic repellents (i.e. selenium) have shown some promise (Angradi 1986) but more research is needed.

Traditional 8 foot woven wire, although effective if maintained, is much too expensive to justify its use for forest management, but, there is considerable interest in the use of electric fencing to protect hardwood regeneration. My company has developed a less expensive but effective electric fence that has been used since 1979 (Brenneman 1983, Kochel and Brenneman 1987). Currently there are more than 3,000 acres of our forest land surrounded by electric fencing in an effort to regenerate hardwoods.

The electric fence we use has five strands of wire and is 58 inches high. The bottom strand is approximately 10 inches off the ground and the other four strands are at 12 inch intervals (Figure 1). High-tensile, class 3 galvanized, steel wire of 12.5 or 14 gauge is used. Plastic insulators and line springs make a strong yet flexible fence. The fence is powered by a battery operated, low impedance energizer capable of 5,800 volts and 65 pulses per minute. A 12-volt deep discharge, marine type battery with at least 100 amphere-hours capacity is used to provide power to the energizer. Batteries need to be changed approximately once each month to

maintain a consistent fence charge. Solar panels and a wind generator have also been used in conjunction with the batteries.

The cost of constructing a 5-strand electric fence is $39.15 per acre or $0.32 per linear foot. Materials account for $21.59 per acre or $0.18 per linear foot and labor to construct the fence $17.56 per acre or $0.14 per linear foot. Annual routine maintenance costs are estimated to be $3.50 per acre.

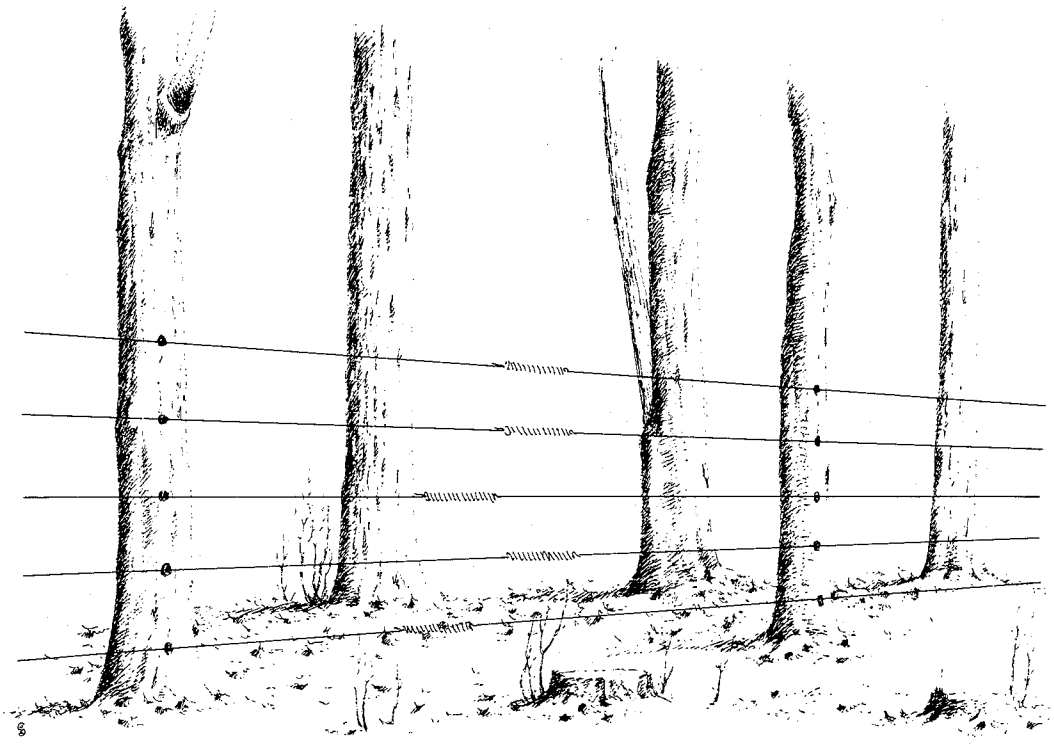

Figure 1. Five-strand electric deer fence.

This fence is not deer proof but it has reduced deer browsing enough that it is possible to get successful forest regeneration. In 1985 and 1986 the regeneration in 22 of the companies fenced clearcuts was inventoried. We used 6-foot-radius circular plots and took a minimum of 20 sample plots per stand up to 20 acres. Another plot is added for each additional 5 acres above 20 acres, i.e. a 50-acre stand could have 26 sample plots. Eighty percent of these clearcuts met the accepted regeneration criteria for successfully regenerating clearcuts. Our criteria is that 70 percent of the regeneration plots contain at least 25 stems per plot total, 5 stems over 3 feet tall or 2 stems over 5 feet tall. More than 89 percent of all the seedlings were of commercial species and there was an average of 25,000 commercial seedlings per acre.

Even though electric fencing is less costly than 8 foot woven wire, a landowner certainly does not want to use it when it is not necessary. To provide our foresters with some direction deciding when to use electric fencing the guidelines found in Figures 2 and 3 were developed for Pennsylvania and New York.

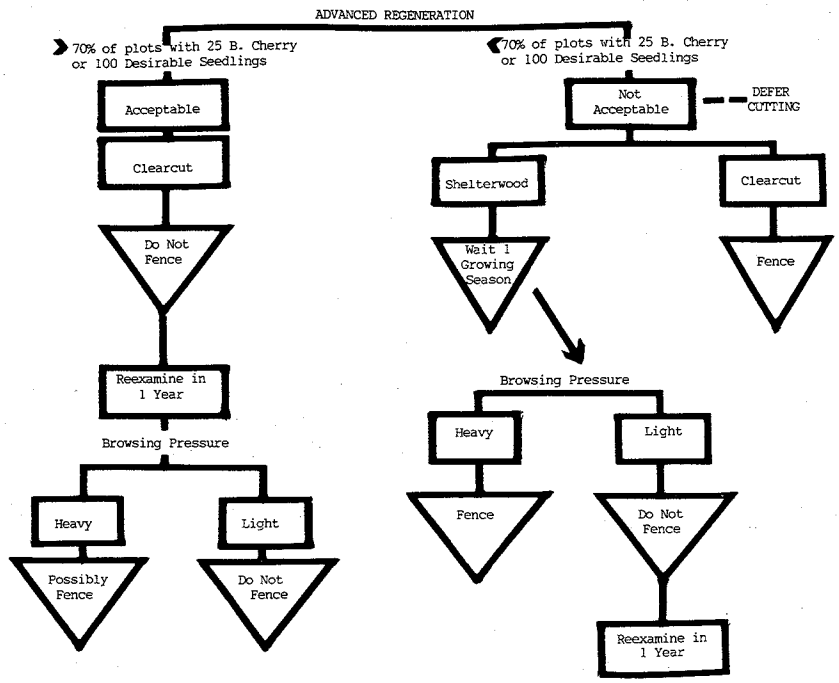

Figure 2. Pennsylvania fencing guidelines.

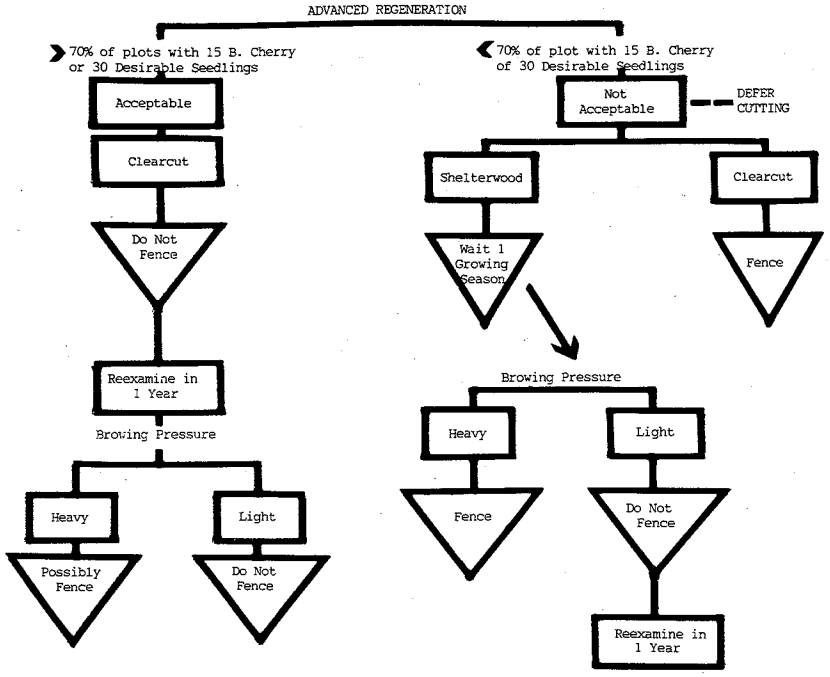

Figure 3. New York fencing guidelines.

Recommendations

When managing a hardwood forest and deer browsing is negatively impacting your management, the following recommendations may alleviate some of the problems. The recommendations should be followed in sequence. In general as you proceed through the list of recommendations the cost of the control measures increases. In some situations it may be necessary to proceed with one or more of the recommendations concurrently i.e. develop a hunting program and establish openings, or develop a hunting program and use some electric fencing until hunting can reduce deer numbers.

1. Reduce the number of deer by allowing or encouraging hunting, especially of antlerless deer. Where possible consider lease hunting as an alternative to public hunting to provide greater flexibility in harvests.

2. Modify deer behavior and reduce browsing on hardwood regeneration by establishing forest openings (0.25 to 1.5 acres). Distribute openings so that they are within the home range of most of the deer.

3. Protect the regeneration by constructing a 5-strand electric fence.

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EFFECTS OF SEED-EATING BIRDS AND MAMMALS ON APPALACHIAN HARDWOOD REGENERATION

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ABSTRACT

The consumption and dispersal of seeds by animals are important processes in Appalachian forests. Seeds and fruits are sources of nutrients and energy for many animals; animals disperse most nut- and fruit-producing plant species. Blue jays and squirrels disperse acorns and other nuts by burying them in the forest floor. The seeds of fruit-producing plants are dispersed primarily by birds. Seed consumption by animals does not appear to cause regeneration failure. Dispersal by animals allows oaks and other heavy seeded species to invade new habitats rapidly. The relationships among seed predators, seed dispersers, and plants are complex; they involve much of the plant and animal community. Managing Appalachian forests for quality sawtimber appears to be compatible with maintaining populations of plants and the animals that eat and disperse seeds.

Introduction

At least 32 species of birds and 12 species of mammals regularly eat the fruit, nuts, and seeds of forest vegetation in the Appalachians. Animals that eat and kill seeds are seed predators, and animals that carry viable seeds away from the parent plant are seed dispersers. Many animal species function as both seed predators and dispersers. Some rodents and one bird species disperse seeds and nuts by burying them in the forest floor. Many birds eat fruits and then pass the seeds in viable condition. In temperate communities, about 60 percent of the tree species and most shrubs, vines, and herbs producing fleshy fruits are dispersed by vertebrates (Howe and Smallwood 1982).

Seed dispersal and seed predation have been the subject of a growing body of research; good reviews are provided by Howe and Smallwood (1982), Janzen (1971, 1983), and C. C. Smith (1975). Most of this research has emphasized selective forces or evolutionary aspects of seed dispersal. The food habits of seed dispersers have been extensively studied, but usually not from the viewpoint of their effects on plants. Relatively few studies of seed dispersal appear in the traditional forestry literature.

My objective is to summarize the literature on seed predation and dispersal that pertains to the regeneration of Appalachian hardwoods. I will briefly describe the major mechanisms of seed dispersal by vertebrates, and then answer some obvious questions about the effects of seed predation and dispersal on regeneration.

Mechanisms of Seed Dispersal

Vertebrates disperse seeds in three ways: they intentionally store seeds for later consumption; they pass viable seeds through the gut after having eaten the fleshy fruit; and they passively carry seeds that cling to their fur or feathers. The first two mechanisms are common in eastern forests, but I found nothing about the transport of "burrs" on fur or feathers of animals.

Nuts and some pine seeds are dispersed primarily by intentional hoarding. Blue jays typify this process (Johnson and Adkisson 1986). In late summer and early fall, jays congregate in areas with abundant mast. They eat some acorns and transport many undamaged nuts back to their territories. Jays have an expandable throat and esophagus and can transport three to five acorns or up to 14 beechnuts at one time. "Upon arrival in its territory, a jay disgorges the nuts into a pile on the ground. It then selects a single nut and either hops or flys a few yards to a caching spot, where it hides the nut by pushing it into soft soil or tucking it under grass" (Johnson and Adkisson 1986).

The process of burying individual nuts in widely scattered locations is termed "scatterhoarding" (Stapanian and Smith 1978). In addition to jays, gray squirrels and fox squirrels scatterhoard nuts. Chipmunks, deer mice, white-footed mice, and red-backed voles hoard seeds, but their caches, which usually consist of many seeds, are occasionally placed in sites unsuitable for germination.

Scatterhoarding individual nuts is probably the most effective system of dispersing heavy seeds. The seeds of fleshy fruited plants are generally dispersed by vertebrates after passage through the digestive tract. Within the eastern deciduous forest over 125 species of trees, shrubs, and vines produce fruits, the seeds of which are dispersed primarily by birds (Stiles 1980). Fleshy fruits are a major source of energy and nutrients for migrating birds (Johnson et al. 1985). The peak of fruit production in the Appalachians occurs during late August and September, and coincides with the

peak migration of birds. Mammals and non-migratory birds disperse the seeds of fruiting plants from early summer through late winter.

Theoretically, dispersal of seeds by vertebrates confers the following benefits on the parent plant:

1. Seeds are removed from direct competition with the parent;

2. Seeds are protected from predation;

3. Seeds are placed where they are likely to germinate; and

4. Plants are able to colonize newly available habitats.

The relationships among dispersers and plants are complex. No vertebrate disperses only one plant species. Communities of predators and dispersers interact with communities of plants.

At present, a good deal is known about the animals that disperse seeds. Less is known about the movements of seeds during dispersal, and little is known about the fate of dispersed seeds. Thus, we can not quantify the impact of vertebrate seed dispersal on the structure and composition of Appalachian forests.

How Prevalent is Vertebrate Seed Dispersal?

In eastern deciduous forests, vertebrates disperse all nut-producing trees; about 125 species of fruit-producing shrubs, vines, and trees; and most summer-fruiting herbs. Both pioneer and climax species are involved. Birds and mammals have generally been considered the primary animal agents of plant dispersal (Krefting and Roe 1949). Recently, box turtles have been identified as potential agents for seed dispersal (Braun and Brooks 1987), and ants have been identified as dispersers of about 30 percent of the herbaceous flora in mesic deciduous forests in West Virginia (Beattie and Culver 1981). The herbs dispersed by ants are mostly spring wildflowers, which fruit before the fall bird migration. Ant dispersal places these seeds in microsites favorable for germination and protects them from predation by rodents (Heithaus 1981). In sum, seed dispersal by animals involves a large component of the plant and animal community and complex interactions among plants, predators, and dispersers. Seed dispersal by vertebrates must be viewed as an important process in Appalachian hardwood communities.

Animals move large quantities of seed. It is extremely difficult, however, to quantify the proportion of dispersed seeds that are ultimately lost to predation versus those that survive. Birds frequently remove entire crops of late summer and fall fruits (Stiles 1980; Thompson and Willson 1979). Birds generally select ripe fruits and defecate or regurgitate many viable seeds (Krefting and Roe 1949). The foraging patterns of migrating birds place many seeds in microsites suitable for germination and survival (Hoppes

1987, Livingston 1972). I found no studies for the Appalachian region, but efficient dispersal by birds and successful colonization has been demonstrated for black cherry, river-bank grape, panicled dogwood, black raspberry, Allegheny blackberry, and bittersweet nightshade in Illinois (Smith, A. J. 1975) and blackberries and cherry in Europe (Herrea and Jordano 1981; Jordano 1982). At present, it seems reasonable to conclude that most fruit producing trees and shrubs rely on birds to disperse their seeds (Johnson et al. 1985).

The dispersal of nuts differs from that of fruits because the dispersing animals are also important predators of nuts. Despite this difference, it appears that jays and squirrels are the primary dispersers of nut-bearing trees in the eastern deciduous forest. Both jays and squirrels scatterhoard large numbers of nuts. During a 28-day period, blue jays transported and cached 133,000 acorns from a stand of pin oak trees in Blacksburg, Virginia. This represented 54 percent of the total mast crop; 20 percent of the mast crop was eaten by jays at the collecting site (Darley-Hill and Johnson 1981). Both jays and squirrels transport and hoard only sound nuts. Jays move acorns and other nuts up to 2.5 or 3 miles (Johnson and Adkinson 1986). Squirrels remove nuts from beneath the crowns of parent trees but usually carry them less than 650 feet (Barnett 1976). Nuts that are removed from beneath the parent tree and cached are protected from predation by wild turkey, white-tailed deer, and other mammals (Barnett 1977).

Both jays and squirrels recover a high proportion of the nuts they hoard (Bossema 1979; Johnson and Adkisson 1986; Sork 1983). It might appear that vertebrates are poor dispersers of nuts because they consume so much of the crop. However, it is important to remember that wind dispersal also kills most seeds by depositing them in the wrong habitat.

Do Seed Predators Cause Regeneration Failures?

Seed predation does not appear to be an important factor in the regeneration of Appalachian hardwoods. I found no indication that seed predation influenced the regeneration of cove and cherry-maple forest types, and just one reference to acorn predation as a cause of oak regeneration failure (Marquis, Eckert, and Roach 1976). Lack of viable acorns appeared to be the primary cause of oak advance regeneration failure in one area in Pennsylvania (Marquis, Eckert, and Roach 1976). High rates of acorn insect infestation and rodent predation were responsible for the loss of acorns.

Although many animals and insects eat acorns, most evidence indicates that acorn production is adequate and seedling survival is the more critical factor. Oak regeneration beneath 59 mature oak stands in West Virginia ranged from 125 to 55,700 seedlings per acre; half of the stands had 2,500 or more oak seedlings per acre (Carvell and Tryon 1961). There was little difference in total acorn and sound acorn production between stands with high and low numbers of oak seedlings (Tryon and Carvell 1958). Most oak seedlings were less than 1 foot tall, and their abundance decreased rapidly with increasing height. The degree of disturbance during the past 20 years

was closely related to the amount of oak regeneration in these stands (Carvell and Tryon 1961).

Abundant oak regeneration and high numbers of acorn consumers can occur in the same stand. I found an average of 1,540 oak seedlings per acre in 1984 and 1985 in 12 upland oak stands in central Massachusetts. White-tailed deer density in this area averaged 40 per square mile in November 1984 and 59 per square mile in November 1985. Gray squirrel populations averaged only 8 per square mile in 1984, but had increased to 98 per square mile in 1985. Blue jays, chipmunks, and white-footed mice were also abundant in these stands. Acorn production was adequate to maintain these wildlife populations and produce reasonable numbers of seedlings. However, oak seedlings seldom grew to large size because of browsing by deer.

Does Seed Dispersal by Vertebrates Affect Forest Management?

The most pronounced effect of seed dispersal by vertebrates is that it enables heavy seeded species to quickly colonize new habitats. This effect is so widespread that it is often overlooked. Pine management on the southern coastal plain usually involves intensive site preparation and subsequent hardwood control. Yet, by the end of the rotation, wildlife has usually reestablished oak, hickory, pecan, and other hardwoods in these plantations.

Animals obviously played a role in the reforestation of much eastern farm land that has been abandoned during the past hundred years. The town of Grafton in southern Vermont, provides a good example of the history of land clearing and natural reforestation (Back 1976). In 1873, the 3,032-acre town was 80 percent farmland. By 1939 it was 65 percent forested and in 1974 about 90 percent of the area was forested. Except for a few plantations established in the 1930's, reforestation was the product of natural succession occurring on abandoned crop and pasture land. Today's stands are a rich mixture of heavy and light seeded species from the northern hardwood and oak-hickory forest associations.

An examination of pollen records shows that for 12 genera of eastern trees, seed size was not significantly correlated with rate of colonization after the last glaciation (Davis 1976; Howe and Smallwood 1982). The oaks were among the most rapid colonizers following the retreat of the glaciers. Jays and squirrels are probably responsible for most long distance transport of heavy seeds.

I suspect that seed dispersal by animals is partly responsible for shifts in species composition that often occur after natural disturbances or our own regeneration attempts. There is an old adage that oak follows pine and pine follows oak. Although I found no experimental proof of the adage, I did uncover some provocative observations. Gray squirrel activity beneath mature oaks and hickories in mixed conifer-hardwood stands in New Hampshire enhanced the establishment of white pine seedlings. When digging to bury or recover nuts, gray squirrels inadvertently covered white pine seed, thus affording it a suitable seed bed and protection from conifer seed predators

(Alexander and Olson 1980). Blue jays carry acorns away from parent trees and tend to bury them in places with thin litter, low vegetation, and full exposure to sun (Darley-Hill and Johnson 1981). Thus, the old adage appears to have a biological basis.

Summary and Recommendations

Seed dispersal by vertebrates involves a complex set of interactions among plants, seed predators, and seed dispersers. The literature on seed dispersal is widely scattered. At present, not much of our knowledge about seed dispersal is applicable to silvicultural practice. However, a knowledge of seed dispersal does help us understand some phenomena commonly observed in Appalachian forests.

Animals are important to the natural regeneration of Appalachian forests, and the seeds and fruits of forest plants are important foods for many animal species. Seed dispersal by animals affects all levels of the plant community. Blue jays and squirrels are particularly important for disseminating the heavy seeds of oaks, hickories, and other nut producing trees. Most plants dispersed by vertebrates are not commercially valuable, yet they are important components of the forest community. Blackberries and pin cherry, for example, are important for maintaining stability in forest ecosystems.

Seed consumption by animals does not appear to be an important cause of regeneration failure in Appalachian forests. Abundant populations of seed consumers and dispersers appear to be compatible with good regeneration.

Managing Appalachian hardwoods for quality sawtimber appears to be consistent with maintaining abundant wildlife populations and obtaining good regeneration of the entire plant community.

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HERBICIDE AND NONCHEMICAL VEGETATION CONTROL DURING HARDWOOD REGENERATION

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ABSTRACT

Alternatives for controlling unwanted vegetation during regeneration of Appalachian hardwood stands are discussed. Techniques that combine forest weed control activities with other stand entries are most efficient. The use of herbicides, as well as nonchemical vegetation management methods like biological weed control, is reviewed. Public safety and the public's perception of risk from herbicide use in forests are evaluated.

Introduction

As the relative value of a resource increases, the intensity with which it is managed increases accordingly. The utilization of all North American forest types has followed this general pattern and the Appalachian hardwood forest (AHF) is no exception. The utilization of the AHF has passed from the mining stage into the managed forest stage, and for some species like black walnut, it has even reached the domesticated phase that differs very little from the management of agricultural row crops. Vegetation management has been the cornerstone of all intensified efforts to improve the production of agricultural and forest crops. In the most basic terms, vegetation management is the use of herbicides and other cultural tools to redirect site resources from unwanted vegetation to the crop species of interest.

The use of herbicides for vegetation management in the AHF presents some unique challenges. The first is selectivity, the toxic effect on target plants without damage to crop plants. Herbicides have been developed that, when used as a broadcast treatment, can completely eliminate broadleaf herbaceous weeds in a broadleaf crop like soybeans without damage. Herbicides can effectively control hardwoods in a pine stand without pine mortality. However, no herbicides are available that can remove weedy hardwoods from AHF stands without substantial damage to the crop hardwood species. Therefore, selectivity in AHF stands is a function of the timing of herbicide applications and the placement of herbicides in such a way that the crop species cannot absorb them.

The second major challenge is the inadequacy of vegetation management response data. Other than the pioneering work of Loftis (1978; 1985) and Horsley (1981; 1982) little data exist on the yield response of hardwoods to vegetation management. Unlike agricultural crops, for which mountains of response to weed control data can be generated in a single year, the accumulation of yield response data for AHF stands takes decades. Less than half of the rotation length necessary for the production of hardwood sawtimber has passed since the introduction of herbicide use for forest vegetation management in the late 50's. Without adequate yield response data, investment analysis for vegetation management treatments in AHFs is an academic exercise without true substance. Luckily, the magnitude of the initial response of hardwoods to woody and herbaceous weed control is so great and the failure of hardwood plantations without adequate weed control is so obvious, that the benefits could only be discounted by the ultimate pessimist. Still, the early results do not provide complete confidence (carte blanche), and extreme caution in financial analysis should be exercised before any vegetation management program is initiated.

The focus of this paper is vegetation management for hardwood regeneration; however, it is far from an all-encompassing review. In fact, this report is designed as a supplement to the paper entitled "Herbicides and application techniques for managing immature hardwoods" published in the proceedings on managing immature hardwood stands two years ago (Zedaker 1986). In that paper, I emphasized the continuous nature of vegetation management for hardwood production. As such, all of the application techniques, herbicides, and safety information in that report are applicable to hardwood regeneration as well as the management of immature stands. Rather than repeat that information, I have attempted to build on it with emphasis on the special requirements of regeneration. Familiarity with the 1986 paper is a prerequisite to complete understanding and utilization of this report.

Uneven-aged Regeneration

The use of vegetation management for uneven-aged regeneration is the least understood practice, even in the more intensively managed coniferous forests of the South and the Pacific Northwest. If timber production is the main goal of management, presumably, uneven-aged management is practiced in stands where relatively tolerant tree species are the crop. A small regeneration gap created by the removal of one, or just a few, canopy trees is all that is needed to ensure regeneration success. Therefore, the creation of large regeneration gaps necessary for intolerant trees is avoided, and there is no need for vegetation management. A common assumption is that the desired tolerant tree will grow at the same rate regardless of its degree of freedom from competition. This assumption has been proven, time and time again, to be false, since slow growth is most often a result of a tree's environment rather than its genetic makeup.

Only rarely have classified tolerants been observed growing in an environment free of competition. Once established, few tolerant hardwoods will grow faster with overhead shade than without. The growth of the advanced regeneration or the stump sprouts into the regeneration gap can be greatly accelerated by controlling competing stems.

Uneven-aged management provides the perfect opportunity to practice continuous vegetation management since the stand will be entered many times during a regeneration cycle and each time, a large percentage of the stand will be visited. Combining a low-intensity vegetation management treatment with a marking or harvest operation would be an efficient use of the time and effort spent moving through the stand. The person(s) carrying out the felling or marking can perform a vegetation management treatment concurrently. Emphasis should be placed on the removal of a certain percentage of the cull or undesirable hardwood species stems at each entry. In addition, special problems like grapevines can be attended to, a little bit at a time, saving the cost of an additional stand entry.

During harvests, the most basic vegetation management treatment that can be done is to cut or chainsaw girdle additional nonmerchantable or undesirable stems. Felling costs for the undesirable stems will be marginally lower per stem or unit of basal area since there is little care about breakage or direction to facilitate yarding. Cutting during the growing season will reduce sprouting of the undesirable species but will also reduce the number and vigor of stump sprouts of the desirable species (Kays et al. 1988). Hardwood species differ greatly in their sprouting response. Some species exhibit bell-shaped sprouting responses with regard to stem size or age while others, like sourwood, sprout very vigorously regardless of size or age. Cutting alone is sufficient to control many woody vines like wild grape (Smith and Lamson 1986).

The best defense against the resprouting of undesirable stems is to treat the surface of the cut stems with herbicides (Table 1). Treating just the cambial surface of the cut stump results in very low herbicide use rates (0.64 to 0.73 gallons per 100 square feet of basal area). Undiluted glyphosate (Roundup), picloram+2,4-D (Tordon RTU), and triclopyr (Garlon 3A) are equally effective in reducing sprouting in most hardwoods. However, picloram+2,4-D is most cost effective (Zedaker et al. 1987). The necessary equipment is minimal, consisting of a small household squirt bottle that can be attached to the feller's belt. Time lost during the felling operation as a result of the stump treatment is only 5 to 10 seconds per tree.

Table 1. Characteristics of herbicides used in vegetation management for hardwood regeneration.

Herbicide				
Common name	Trade name(s)	Formulation[a/]	Use[b/]	Toxicity class[c/]
2,4-D	DMA-4, Formula 4D Esteron 99, Weed Rap Weedone 64	SL,EC	I,ST,BS FS	Moderate
2,4-DP	Weedone 2,4-DP Weedone 170, Weedone CB	SL,EC	I,ST,BS, FS	Moderate
Dicamba	Banvel, Banvel CST	SL,EC	I,ST,BS, FS	Slight
Fosamine	Krenite	SL	I,FS	Non-toxic
Glyphosate	Roundup, Accord	SL	I,ST,FS	Slight
Hexazinone	Velpar L, Pronone, Buckshot	SL,G,P	I,FS,SA	Slight
Imazapyr	Arsenal	SL	FS	
MSMA	Transvert	SL	I	Slight
Picloram	Tordon K, Tordon RTU	SL	I,ST,BS, SA	Relatively non-toxic
Triclopyr	Garlon 3A, Garlon 4	SL,EC	I,ST,BS, FS	Slight

[a/] S - Soluble liquid, EC - emulsifiable concentrate, G - granular, P - pellet.

[b/] I - Injection, ST - stump treatment, BS - basal spray, FS - foliar spray, SA - soil application.

[c/] EPA toxicity classes.

During a marking operation, the most efficient vegetation management treatment would be the injection of undesirable stems using a hypo-hatchet. Injection with the hypo-hatchet is more efficient than with other injection tools and can be accomplished while carrying a tree marking paint stick or gun (Wiltrout 1976). The injector and herbicide reservoir are both carried in holsters attached to a belt when not in use, freeing the hands for tree marking. Production rates of 25 to 50 square feet of basal area treated per hour are normal for moderate (<30 percent) slopes in pole and small sawtimber-sized stands. The herbicide 2,4-D is the least expensive for injection but it has notable weed species weaknesses. Combinations of 2,4-D with picloram or with glyphosate provide a wider spectrum of weed species control and are therefore preferred (Zedaker 1986). Injection treatments made during the late summer and early fall are most effective (Kossuth et al. 1980). Weed trees could also be girdled (cutting through the cambium in a band completely around the tree) without the use of herbicides, but profuse sprouting will usually occur. Also many species will overgrow the girdle if it is not absolutely complete. This ineffectiveness combined with the time, physical effort, and extreme danger involved in girdling trees with hand tools or chain saws has all but eliminated girdling as a viable vegetation management tool.

Even-aged Regeneration

The magnitude and type of vegetation management treatments needed for even-aged regeneration of AHF stands are largely determined by the source of the desirable regeneration and the density and size of undesirable species. If stump sprouts are to be the major source and weed species density is low, little vegetation management effort will be needed. If seedlings or seedling sprouts are to be the major source and weed density is high, vegetation management will be costly.

When sprouts are to be the major source of regeneration, the growth rate of hardwood stump and root sprouts is usually sufficient that competition from weed species, both herbaceous and woody, that are less than 10 feet tall at the time of clearfelling will not result in a regeneration failure. A common practice for AHF stands is to remove the undesirable stems by cutting after the merchantable timber has been removed. However, the growth rate of undesirable stem sprouts usually equals or exceeds that of desirable stems, and a second stand entry, traversing the logging slash with difficulty, is necessary (Loftis 1978). Two solutions to this problem are possible.

1. Inject the undesirable stems in the stand prior to harvest. Significant improvements in the dominance of desirable stems (83 to 92 percent for pre-harvest injected stands versus 65 to 69 percent for post-harvest felled stands) have been demonstrated using this technique (Loftis 1985).

2. Use felling and cut-stump herbicide treatment of undesirable stems as the merchantable stems are harvested (Zedaker et al 1987). Cut-stump treatment with the best herbicides results in over 60 percent kill and over 90 percent control of sprout crown volume of undesirable species. The loss in felling and yarding productivity during the merchantable stem harvest is more than offset by eliminating additional entries into the stand.

If seedlings and seedling-sprouts are the preferred regeneration, other treatments, in addition to those designed to eliminate undesirable stem sprouting, are often necessary. Competition from understory shrubs, tolerant tree saplings, and ferns and grasses will often impede or completely eliminate seedling reproduction (Horsley 1987). If the density of understory shrub and tolerant tree saplings is high (>1,000 stems per acre), broadcast applications of foliar applied herbicides using mistblowers prior to harvest is probably most efficient. Relatively low rates of glyphosate (<2 pounds ai per acre) have been shown to be effective on a wide variety of hardwood species when applied in the understory (Horsley 1981; D'Anieri et al. 1986). Other foliar-active herbicides like imazapyr (Arsenal), fosamine (Krenite), 2,4-D, and triclopyr may also be effective but are as yet untested in understory applications. Backpack foliar treatment production rates will vary between 0.5 and 2.0 hours per acre, depending on the terrain and the understory density (Zedaker 1986).

If understory shrub and sapling density is low, basal applications are more efficient than broadcast foliar applications. Modified basal applications (5 to 25 percent herbicide in diesel or kerosene applied to a 4-inch band completely around the stem base) are most efficient (Zedaker 1986). Triclopyr, 2,4-D, picloram, and dicamba (Banvel) can be used. As with stem injection, 2,4-D alone is the least expensive but may not be the most cost efficient.

Often, dense communities of ferns, grasses, and broadleaf herbs dominate the understory of AHF stands. These communities can reduce or totally eliminate hardwood seedling regeneration through competition for site resources and allelopathy (Horsley 1977a; 1977b). Backpack foliar broadcast applications of glyphosate and sulfometuron (Oust) have proven effective in controlling these herbaceous weeds and improving desirable hardwood seedling density (Horsley 1982; 1987).

Biological Weed Control

In a general sense, biological weed control is the use of biological principles (silvics) or agents to control unwanted plants. Silviculturalists practice biological weed control whenever they schedule a harvest or prescribe a harvest technique that minimizes the success of weed trees because of their silvical characteristics. However, among weed scientists,

biological weed control means the use of pathogens or insects to lower the population of weeds to the level that they are no longer economically important. Biological weed control has great appeal to the general public that has been misled about the risks of herbicide use. It sounds natural and therefore better than using man-made chemicals. Unfortunately, at least with the current technology, the potential drawbacks of the use of pathogens and insects to control forest weed species far outweigh the potential risks.

To be successful, a biological weed control agent must meet the same criteria as are required for herbicides.

1. The agent must be inexpensive to develop and use.

2. It must be fast acting and offer consistent results.

3. It must not cause any environmental degradation or represent a significant public health hazard by being specific enough in its action or placement as to only impact target weeds.

Biological weed control agents, because they are expensive to develop and supply (relative to forestry herbicides), are released into the environment in relatively small numbers. They spread naturally through the weed species population and may take decades to produce a significant drop in weed populations (Rosenthal et al. 1985). Multiple introductions are often necessary for the successful establishment of control agent populations because of the natural variability in the environmental conditions that control their growth, development, and reproduction. The greatest single disadvantage of biological control agents is that they are, at least currently, only species specific. Unlike herbicides, they are not species-site specific. Since biological control agents currently depend on natural spread for success, these agents cannot be prevented from causing a severe degradation of someone else's environment. Although striped maple may be a weed to a timber producer, it is not so to the homeowner. Thus, judged against the same criteria for successful use applied to herbicides, biological control agents fall far short.

Biological control agents are currently applicable only to introduced weeds that everyone agrees is a weed. Kudzu and Japanese honeysuckle are probably the only AHF weed species that may eventually be controlled by a biological agent. Genetically engineered control agents may eventually be developed that would not depend on natural spread to become effective. However, the general public's record on allowing the release of genetically engineered organisms is already disenchanting. Enhanced allelopathic activity by crop species may also be a potential biological weed control method. Crop species like black walnut are already recognized for their allelopathic capabilities. Enhancing those capabilities may also take genetic engineering or at least genetic selection, which means that plantation forestry in the AHF will be necessary.

Herbicide Safety and Environmental Concerns

In the previous section, I made the statement that the public has been misled about the potential risks of herbicide use; a strong statement, but entirely substantiated by scientific fact. Unfortunately, most forestry professionals are not equipped to re-educate the public and, sadly, many have swallowed the bait as well. The more information we accumulate on herbicide safety and risks the better prepared we will be to alleviate the public's fears with regard to their use.

In my 1986 paper, I provided evidence of the toxicity of herbicides relative to common household chemicals. The herbicides 2,4-D and 2,4-DP, classified by the EPA as moderately toxic, are about as toxic as caffeine and rubber cement but much less toxic than common laundry bleach. Most forestry herbicides are classified in the slightly toxic group, making them equal to aspirin, liquid detergent, and table salt in acute toxicity. A few, like MSMA and fosamine, are equal in toxicity to relatively nontoxic household chemicals like baby oil.

To the rational human, these facts should create the perception that herbicides are relatively safe compounds. Unfortunately, these data have not been presented to the public and their perception is that pesticides are much more dangerous than they actually are (Figure 1). In a recent survey, college students, women voters, and business people ranked the risk of accidental death from pesticides far in excess of the actual risk. Most startling, college students (our future leaders) ranked pesticides as more dangerous than riding motorcycles (Barrons 1987). Our only conclusion can be that the public has been grossly misinformed.

The most likely explanation is that the public is reacting to published information or news reports connecting the use of the phenoxy herbicides (2,4-D and 2,4,5-T) to spontaneous abortions and to cancer (EPA 1979; Hoar et al. 1986). In 1979, the EPA reported that women living in Alsea, Oregon, were experiencing an unusually high rate of spontaneous abortions as a result of exposure to 2,4,5-T from forestry applications. Even though the findings of the Alsea II report were scientifically proven to be false by Wagner et al. (1979), a finding not reported by news media, 2,4,5-T was suspended and eventually deregistered. More recently, Hoar and others (1986) reported a possible association between the use of 2,4-D by Kansas farmers and non-Hodgkin's lymphoma. An EPA official indicated to the news media that the Kansas report may lead to the suspension of 2,4-D while their own scientific review of the study concluded that no association could be found. Again, scientific critique of the Kansas study has not found its way into the popular press. No pesticide can be used if it is ever proven, or even suspected, to cause cancer, chromosomal aberration, or birth defects, at any level.

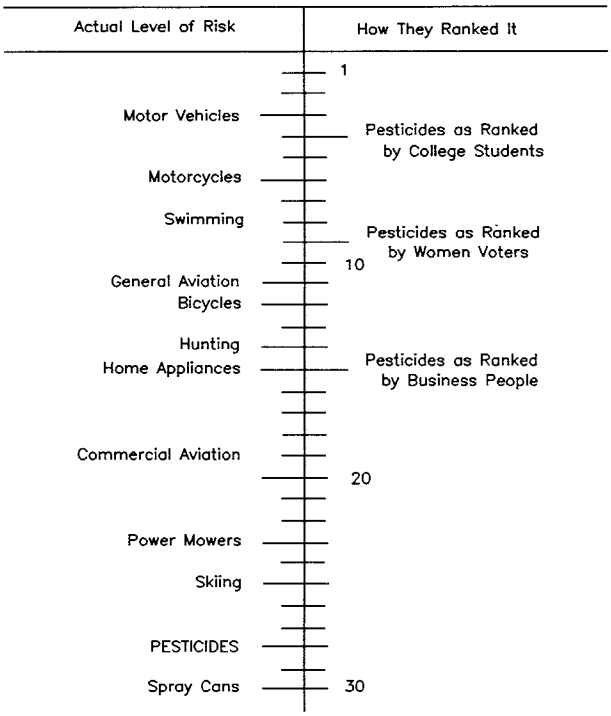

Figure 1. Rating the pesticide risk. On the left are actual levels of risk risk of accidental death from various causes as established for insurance purposes. On the right are the risks from pesticides as ranked by college students, women voters, and business people.

The evaluation of risk must account for exposure as well as toxicity. Saccharine in diet pop, caffeine in coffee, furocoumarins in celery, alkaloids in herbs and honey, aflatoxin in peanut butter are just a few of the many dietary carcinogens that the public accepts because they perceive that their risk is low due to a lack of exposure. In my 1986 report, I provided data (Zedaker 1986--Table 9) that proves the general public is in no danger from forestry herbicides as a result of excessive exposure. As an example, to reach the NOEL for 2,4-D with a 100-fold safety factor (NOEL/100), a 132-pound person would have to drink 32 gallons of stream water or eat 284 pounds of venison, contaminated with 2,4-D at the highest concentrations ever recorded, every day of that person's life. NOEL/100 is an amount of chemical 100 times less than the lowest amount known to cause any observable effect in test animals in chronic (life time) feeding studies.

Clearly, only the applicators seem at some risk. To reach the same NOEL/100 an applicator need only ingest 0.017 ounce of spray solution per day. However, recent work by Lavey and others (1984) indicates that the safety

margins for applicators are also quite large (Figure 2). In a study involving 80 forestry herbicide applicators using 2,4-D, 2,4-DP, and picloram for backpack spraying and injection work, the average margin of safety ranged from 245 to 5,581 for 2,4-D. For those using picloram, the margins of safety ranged from 23,000 to 943,400. Only one worker, whose clothing was saturated with spray, had a safety margin less than 100 (actually 98). It seems, as Roosevelt said,"we have nothing to fear but fear itself."

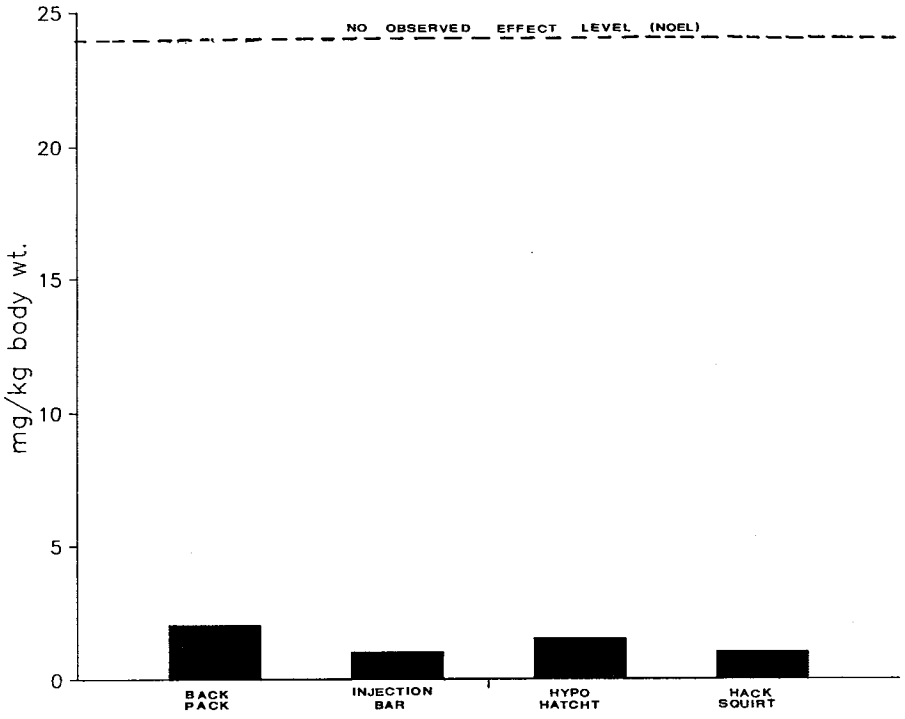

Figure 2. Actual exposure (observed absorbed dose) of forestry workers to 2,4-D using four application techniques. (From Lavey et al. 1984).

Summary

There are many opportunities available for the use of vegetation management treatments to improve regeneration in the AHF. Treatments utilizing herbicides are usually more effective than mechanical treatments alone. And, contrary to popular belief, the proper use of herbicides does not constitute a significant health hazard to the general public or the applicators. The value of most AHF stands does not warrant intensive vegetation management treatment. Low-intensity treatments, carried out in conjunction with other stand entries, offer the greatest opportunities to economically improve regeneration success.

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EVEN-AGE MANAGEMENT PRACTICES FOR REGENERATING APPALACHIAN HARDWOOD STANDS

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Abstract

Common even-age harvest practices are defined and general applications discussed as related to the oak, cherry-maple, and cove hardwood forest types. Using experience based on an industrial cooperative forest management program with private landowners, examples are provided to show how silvicultural harvesting practices are influenced by landowner objectives, economics, logging contractors, and foresters.

Introduction

Like most professions, forestry has its own terminology. As in other branches of science, we commonly use, and even abuse this terminology in conversation. Recognizing this tendency, it may be prudent to begin with a few definitions (Society of American Foresters 1987).

1. Even-aged system--silvicultural systems in which stands have an even-aged structure (a stand of trees having a range of ages not exceeding 20 percent of rotation age).

2. Clearcutting method--a method of regenerating a forest stand in which all trees on the area to be regenerated are removed in one cutting, leading to the development of an even-aged stand either by natural seeding or by planting. Clearcutting may be done in blocks, strips, or patches.

3. Shelterwood method--a method of regenerating a forest stand in which the mature crop is removed in two or more successive harvests such that a canopy of trees is left to provide shelter for the regeneration. The objective is to create an even-aged stand. The harvest may consist of three parts: 1) a preparatory cut to encourage seed production; 2) a seed cut to open up the stand, prepare the seed bed, and allow regeneration to become established; and 3) a removal cut (or final cut) to remove the shelter so that the established

seedlings can develop. The harvest may be done uniformly throughout the stand, in strips, or in groups.

4. Seed-tree method--a method of regenerating a forest stand where all trees are removed from the area except for a small number of seed-bearing trees that are left singly or in small groups. The objective is to create an even-aged stand. The seed trees are removed when regeneration is established.

5. Coppice method--a method of regenerating a forest stand in which the trees produce sprouts or suckers.

Even-Aged Systems

The clearcutting method is used for the oak, cherry-maple, and cove hardwood forest when:

1. Stand has an adequate understory present.

2. Intolerant species are desirable.

3. Stand has slow tree growth rates and has or is approaching stagnation.

4. Trees in stand exhibit strong tendency to produce epicormic branches.

5. Stand conversion to pine is desirable.

6. Due to effects of repeated high-grading, stand needs a fresh start of seedlings and low-origin sprouts.

7. As a result of fire, insects, wind, etc., stand needs a salvage cut.

Shelterwood is used when:

1. Advanced reproduction is inadequate.

2. The first, or regeneration cut is profitable.

3. Residual trees will benefit from release. In other words, the ingrowth and the value added to residuals will be worth more than the present clearcutting of the stand.

4. The final harvest removal cut will be profitable.

Shelterwood is used more frequently in mixed oak and cove hardwood stands.

1. In mixed oak stands, normally 50 percent of the crown density is removed. The harvest is concentrated on intermediates and weaker codominants. The removal cut is delayed until the overstory inhibits the understory (6 to 15 years) and performed while the developing reproduction stems and saplings are still flexible.

2. In cove hardwood stands, harvest guidelines are similar to those in mixed oak. Shelterwood can be used to control the explosion of herbaceous material. It can also be prescribed when the maturity rates of associated species differ. For example, harvest mature yellow-poplar in the first cut and remove oaks 12 to 15 years later.

The seed tree method is seldom used:

1. When used, as in Virginia, seed trees are primarily used to comply with local laws. Virginia has a seed tree law for yellow-poplar, white pine, loblolly pine, shortleaf pine, and pond pine. When anyone of these species represents more than 10 percent of the stand, a seed tree cut is required. Two trees per acre per species are left for seed tree purposes. These seed trees are removed.

2. Use seed tree practice in mixed oak-white pine stands to promote white pine.

3. Generally, the seed tree practice is not used in hardwoods because:

   a. Seed production is unpredictable.

   b. Seed usually remains viable in litter layer for a few to several years.

   c. Seed trees lose quality and tree value.

   d. Overstory canopy is too sparse to influence regeneration.

Cooperative Forest Management (CFM)

Most of my experience has been managing private woodlands through Westvaco's CFM program. I will discuss some of my experiences and thoughts, but first I want to give you some background about this program.

Westvaco's CFM Program is a landowner assistance program that began in 1956 in Charleston, SC. A formalized CFM program was adopted in the Covington area in 1974. The Covington region now has close to 500 private cooperators in the program. This program encompasses over 400,000 acres of woodland in

26 counties of Virginia and six counties of West Virginia surrounding the Covington, VA, papermill.

Timber type and site quality range dramatically within this area. Higher quality northern hardwood and cove hardwood stands are found in West Virginia. Mixed oak stands become more prevalent as one travels east through the Greenbrier Valley, the shaley ridges of the Covington area, and the Shenandoah Valley of Virginia. East of the Blue Ridge Mountains, mixed oak-pine and pine plantations are common in the upper Piedmont area of Virginia.

CFM's role in association with these 500 landowners is principally one of advisor and expeditor. We advise landowners how to best manage their timber resource based on the character of that resource and the owners' personal objectives. We expedite the management of the resource by assisting them in the placement of wood products on the market.

Methods and Landowners

Because CFM acts as an advisor to a landowner and technically has no decision making capabilities, often a blend of regeneration methods occur when harvesting timber. Not only are methods within a system used concurrently, but mixes of systems (even-age versus uneven-age) are often used on the same property.

For example:

1. Mr. X has a mature mixed oak stand with a strong white pine understory.

2. A CFM forester recommends a clearcut with care taken during harvesting to leave the understory of white pine seedlings and saplings.

3. Mr. X does not wish to clearcut.

4. A compromise is reached. A heavy individual tree selection is performed in the more visible section of the property and a smaller clearcut is conducted, as a trial, at the far end of the tract.

Non-Industrial Private Forestlands (NIPF) Concerns Influence Silvicultural Considerations

Landowner Desires

The landowner ultimately makes the management decisions based on:

1. Ownership Objectives. These objectives can include land stewardship, profit, wildlife, recreation, esthetics, etc.

2. Financial Position. Is it necessary to show a profit? If so, the amount and the timing of profit are driving forces.

It should be stressed that both of the above considerations can change dramatically, even within one year. Financial position can change momentarily. But landowner objectives may also change through the process of education and experience in managing a timber resource.

For example:

1. After harvesting was completed, Mr. X stated that he had no objection to the clearcut area.

2. In fact, he wished that the selection cut area had been marked more heavily. He requested a second selection cut to be performed in this area and projected that the final cut would take place in the next 10 years.

Now, rather than managing the stand in an uneven-age system, as originally decided, it will become a three-stage shelterwood harvest method and retain its even-age structure.

Profit

Most, if not all, management activity must show a profit. Not many landowners will have trees cut if it is not translated to some money in their pocket. Therefore, even if the best stand silviculture treatment would be an individual tree selection harvest, the treatment must be feasible (profitable) or it will not be conducted. In extreme situations, stand parameters and profit may reduce management options to either clearcutting or leaving the stand to grow (no cutting).

For example:

1. Because a three-stage shelterwood harvest will be accomplished in an average oak stand, one might assume that it was profitable.

2. Yes, in this example, it was feasible because the tract was located less than 15 miles from both a pulpmill woodyard and a sawmill. Had the property been 40, or more miles from these markets, the harvest may not have been accomplished.

In that profit is a controlling force in forest management prescriptions, factors that affect stand profit include the following:

1. Regeneration Method.
2. Size of Harvest Unit.
3. Character of Contractor.

4. Logging Conditions.
5. Stand Accessibility.
6. Distance to Markets.
7. Market Strength.

Logger

One may not feel that the character of a logging contractor has much impact on a silvicultural prescription, but in reality, loggers may indirectly influence or even dictate the prescription.

Not all loggers are able or even willing to perform an adequate uneven-age harvest. An extreme case of the logger influencing a silvicultural recommendation is when a recommendation is modified to fit the contractor's operation. This is common when a landowner has a friend, neighbor, or acquaintance that "will" cut his timber. Through your knowledge of the logging contractor's abilities or, even more important, inabilities, a silvicultural recommendation may need to be changed in order to lessen the impact of that logger on the future stand.

In addition to the abilities of logging contractors to influence a prescription, factors such as their available equipment and even their financial position affect the type of sale a landowner can make and the profit the landowner will realize.

For example:

1. Mr. Y has a large-diameter, overmature mixed hardwood stand of hickory, yellow-poplar, and oak.

2. A forester marks using an individual tree selection method without a commitment from the landowner concerning his future goals. The stand was marked knowing only that the landowner desired money and did not want to clearcut.

3. The sale was bid. It brought a record dollar per acre for the area but few competitive bids were received.

4. The harvest removed approximately 60 percent of the stand.

This example shows two factors influencing the regeneration method. First, the landowner's preference and indecision as to the future stand's complexion. Secondly, the type of sale conducted and the size of the sale area affected the contractors that bid on the sale and thus, the ultimate profit that the landowner received. In this case, the timber sold put the few contractors that had the credit limit to bid on the sale at their credit and psychological limit. Even if the stand was clearcut, the return per acre would not have been significantly greater. It also exemplifies the unenviable position of foresters at times when dealing with landowners. Often we are reacting to a situation rather than trying to control the situation.

Conclusion

Even-age management is the most commonly used system of regenerating hardwoods. The method used depends on many factors. Landowner objectives, economics, logging contractors, and species silvicultural considerations all influence silvicultural treatments used to manage forest stands. Like most forest management decisions, the control of light is the ultimate tool foresters use to manipulate the forest stand. However, in reality, it is often the landowner objectives and/or the financial ramifications of a practice that controls the silvicultural treatment.

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UNEVEN-AGED REGENERATION IN APPALACHIAN HARDWOODS

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ABSTRACT

The decision process used to determine whether to implement an uneven-aged silvicultural system in an Appalachian hardwood stand is complex and requires that the decision-maker have a sound understanding of the dynamic processes involved, both with individual trees and with stand growth and development. It is particularly important to fully understand and evaluate the long-term implications of the present stand conditions, and to fully understand the regulation processes that are to be implemented to ensure that future stand integrity is maintained.The single-tree selection regeneration method is a viable option for developing and maintaining uneven-aged stands where product objectives are oriented toward shade-tolerant Appalachian hardwood species. Guides for the application of single-tree selection have been developed and are available. The group-selection regeneration method is presently being considered for application in Appalachian hardwood stands composed of intermediate and shade-intolerant species. However, implementation procedures for group selection are only in the development stage and are not available for widespread application. The diameter-limit cutting procedure has been widely applied in Appalachian hardwood stands. The effects and long-term implications of using this cutting procedure are highly variable and depend on the condition, structure, and species composition of the stand following the cut. With modifications to the cutting procedure and with careful consideration given to the regeneration and to future stand development, the diameter-limit cutting procedure may be appropriate in managing uneven-aged Appalachian hardwood stands.

Introduction and Background

Harvesting a mature forest crop and regenerating the new stand are inseparable in a management context. Harvesting the final forest crop without full consideration for regeneration is an unacceptable forest

management concept. In Appalachian hardwoods, where natural reproduction is the primary source of regeneration following a final harvest cut, the selection of the regeneration system is a critical management decision and is heavily influenced by the condition and species composition of the present stand. The fact that Appalachian hardwood stands normally consist of eight to ten or more species, each of which has specific and often quite different silvical characteristics, makes the regeneration decision especially critical when uneven-aged silvicultural systems are contemplated. A silvicultural system is formulated in response to a specific set of site, economic, and social/political conditions and is composed of a series of silvicultural treatments that produce a forest that will satisfy the forest management objectives. A silvicultural system includes regenerating, tending, and harvesting a forest stand. This paper will focus on the regeneration aspects of uneven-aged Appalachian hardwood stands.

Uneven-aged refers to a stand with trees of three or more distinct age classes that are well distributed across the rotation length, either intimately mixed or in groups. For the purposes of the present discussion a "forest stand" is defined in a management context as the smallest management unit. The stand, is the land area to which a particular silvicultural manipulation would be applied. If the clearcut method of regeneration (an even-aged regeneration method) were to be applied, then the whole stand would be clearcut at one time and new regeneration obtained. If the single-tree selection regeneration method (an uneven-aged regeneration method) were to be implemented, harvesting and new regeneration would occur at intervals throughout a rotation length. For discussion purposes, a stand would normally range from 15 to 100 acres.

The purpose of implementing an uneven-aged silvicultural system is based on specified management objectives, to establish or perpetuate a forest stand that is made up of single trees or groups of trees that range in age from new seedlings to trees that are mature and ready for harvest. Under uneven-aged management, the stand is maintained above a specified minimum density, tree stem quality and desirable species composition are controlled, and the scheduled harvests yield approximately equal periodic volumes of products during a single rotation length. Trees of differing age are normally segregated horizontally into small substands, varying from one to several hundred stems, depending on age (Smith 1973). When one large tree is removed from a stand, it will normally be replaced by several hundred new seedlings. Through normal competition and mortality the seedlings will be reduced in number over time, until only one or perhaps two mature trees remain at the end of the rotation. In an even-aged stand the main canopy grows and develops vertically as a single, continuous horizontal unit. In an uneven-aged stand the main canopy develops vertically as a series of smaller horizontal units that are separated into as many strata as there are age classes represented in the stand.

The differentiating characteristics that separate an even-aged from an uneven-aged forest are rather arbitrary and have been the fuel for many heated debates. From a regeneration standpoint it seems that the most logical way to differentiate between even-aged and uneven-aged is to base the decision on ecological criteria. The minimum size of an even-aged harvest unit would be based on the microclimatic influences of adjacent trees. The most influential climatic variables are related to solar radiation. When the center of a harvested opening in a forest is no longer under the immediate influence of the adjacent border trees, then the opening is considered to be the minimum size for an even-aged unit. The microclimate, primarily light and temperature, at the center of the minimum-sized clearcut area would be virtually the same as that prevailing in a large clearcut area. This minimum-sized opening would probably have a diameter of about two times the height of adjacent trees but would vary somewhat depending on the opening shape and on the slope, aspect, and topographic position of the particular site. As an example of this ecological definition to separate even-aged from uneven-aged, assume border trees of a harvested area are 80 feet in height. Then the regeneration occurring in any circular opening greater than one-half acre would be considered to be even-aged. In other words, regeneration following a harvest, if not under the direct influence of adjacent border trees, would develop as if it were in a large clearcut and be considered the result of an even-aged regeneration method. Regeneration in a harvested area that is directly influenced by adjacent border trees would be considered to be the result of an uneven-aged regeneration method.

A forest manager's decision to implement an uneven-aged silvicultural system should be based on:

1. Owner objectives.
2. Silvical characteristics of present or desired species.
3. Stand conditions and structure.
4. Site characteristics.

Stand structure refers to the distribution and representation of age/diameter classes; and in a managed, uneven-aged stand, age and diameter are usually closely correlated. In general, stands that already have irregular structure and are made up of species that are shade tolerant are well suited to an uneven-aged silvicultural system. Furthermore, fragile sites, steep slopes, areas with high water tables, and very dry sites that would be adversely affected by complete removal of forest cover are examples of conditions where uneven-aged rather than even-aged silviculture would be applicable (Gibbs 1978).

Within the forest stand, the physical and biological impacts under an even-aged regeneration system are of much greater magnitude than the impacts in a similar stand under an uneven-aged regeneration system. When the owner objectives include a major emphasis on such forest benefits as esthetics (visual impacts), wildlife habitat, watershed considerations, and certain types of outdoor recreation, then uneven-aged silvicultural systems offer

viable management alternatives and should be carefully considered by the forest manager. Visible impacts of even-aged regeneration harvests are more noticeable on the landscape, compared to uneven-aged regeneration harvest cuts that are more subtle and probably not visible at a distance. For visibly sensitive viewsheds and travel influence zones related to wilderness areas and other esthetically sensitive outdoor recreation areas, uneven-aged regeneration systems may be distinctly advantageous. Wildlife habitat under an uneven-aged system would be less variable and would lead to more stable populations of those wildlife species that were adapted to the particular set of conditions that the system created. This could be an advantage or a disadvantage depending on the established wildlife management objectives. As for watershed considerations, if relatively stable water production from a single first- or second-order watershed (approximately 15 to 100 acres) is a management objective, then an uneven-aged silvicultural system is more appropriate.

On a stand basis, over a full rotation period, the access requirements are more demanding for an uneven-aged silvicultural system than for an even-aged system. An uneven-aged system requires more or less continuous access to accomplish the periodic harvests and other cultural operations. Harvesting operations generally require higher quality roads and more intensive maintenance over time than are necessary for most intermediate silvicultural manipulations under an even-aged regeneration system. In an even-aged Appalachian hardwood stand the most likely treatment for the first 20 to 40 years following a regeneration harvest might be some form of crop-tree release, a species control measure, or perhaps a pre-commercial thinning. Any of these early treatments require only minimal access, as there would be no heavy equipment used or product removal required. Road maintenance required for hauling heavy loads and using harvesting machinery would seldom be necessary before the final 30 to 40 percent of the rotation under an even-aged system.

Theoretically, reproduction under uneven-aged silvicultural systems is considered to be of seed origin. In reality, reproduction following the periodic regeneration cuts originates from a combination of sources. Depending on species and conditions, regeneration can develop from seed from adjacent trees, seed stored in the forest floor, advance regeneration, sprouts from cut stumps and broken stems, and/or root sprouts. There is no reason to exclude considering the use of artificial regeneration, provided that the species selected are compatible with the microenvironment conditions that prevail. Artificial regeneration could be used to supplement species already present or to introduce species that are desired; however, there is little information available at this time as to the success of artificial regeneration in uneven-aged stands.

The remainder of this paper will focus on the silvicultural considerations of two uneven-aged regeneration methods, single-tree selection and group selection, and on the diameter-limit cutting method. I do not consider the diameter-limit cutting method to be a regeneration method per se; however,

it is appropriate to discuss the treatment since it is widely applied in Appalachian hardwoods, and the consequences of implementing this harvesting procedure must be fully understood by forest managers.

Uneven-Aged Regeneration Methods

Selection methods of reproduction are uneven-aged regeneration methods that consist of the removal of biologically and/or economically mature timber, usually the oldest or largest trees, either as single, scattered individuals (single-tree selection) or in small groups (group selection) at relatively short intervals (cutting cycles), repeated indefinitely. By means of these methods the continuous establishment of reproduction is encouraged, and an uneven-aged stand is developed or maintained (Smith 1986).

Selection methods of regeneration are not to be confused with "selection cutting," a practice that is used in the eastern hardwood region and refers to the indiscriminate cutting of the largest, most desirable, and highest-value trees and leaving everything else--in other words, the "high-grading" of a stand. The Forestry Handbook (Wenger 1984) precisely expresses my feelings when it states, "It must be stressed that "selective cutting" is a term so corrupted in use that it has become a description of any sort of partial cutting. It is not a technical forestry term."

Cutting Cycles

From a theoretical standpoint, the periodic cutting cycles associated with uneven-aged management could occur annually so that there would be a continuous flow of harvested material. The harvest yield would be equal to the average annual growth of the particular stand. In practice, however, the cycle interval is based on the minimum volume that can be removed economically, on the potential for damage to residual stems, and on site conditions. As an example, if the minimum volume that can be removed economically is 2,500 board feet per acre and the average annual growth is 250 board feet per acre, then the minimum cycle would be 10 years. If the rotation required to meet the desired product size is 70 years and a 10-year cycle length is used, the resulting stand would be uneven-aged with 7 evenly distributed age classes present. Normally, cutting cycle intervals range from 5 to 20 years in length. It is not necessary that successive cycles be the same length so long as the stand structure objectives are maintained.

Species Considerations

Tree species vary greatly in response to the environmental conditions that are produced as a result of implementing different silvicultural treatments. Silvical characteristics that are most important to consider in making uneven-aged management decisions are:

1. Shade tolerance.
2. Growth rate.
3. Longevity.

4. Maximum tree diameter.
5. Density/growth relationships.

In the regeneration phase, shade tolerance is probably the most important factor controlling the initial growth and development of a particular species. The more shade tolerant the species, the more likely that species is to regenerate under conditions of limited light, provided that viable seed is available. Species such as American beech and sugar maple are very shade tolerant, and the potential for regeneration is high with only minimal-sized openings in the main canopy similar to those occurring as a result of single-tree removal. Species such as basswood, red maple, white ash, and sweet birch are tolerant to intermediate in shade tolerance and will be somewhat limited in their ability to regenerate in single-tree-sized openings. Regeneration of species intermediate in tolerance would be more concentrated toward the center of these small openings. Intermediate and shade-intolerant species such as the oaks, hickory, black cherry, and yellow-poplar would exhibit very limited regeneration in single-tree-sized openings. These less tolerant species are best adapted to the group selection method of regeneration where trees are harvested in groups and the openings are large enough to provide light conditions conducive to the regeneration of even the most shade-intolerant species.

The transition from single-tree-sized openings to group-sized openings in Appalachian hardwood stands would normally range in size from perhaps 1/40 to 1/4 acre. Openings greater than 1/2 acre in size would normally reflect environmental conditions similar to those expected in a large clearcut opening. More complete information on the effects of opening size on species development have been reported by Minckler and Woerheide (1965) and Smith (1981). Marquis (1965) reported on light availability as affected by size, shape, and orientation of small forest openings.

The single-tree selection method of regeneration can be implemented in a stand where the present main canopy is composed of species that range from very shade tolerant to very shade intolerant. However, it must be realized that the environment at the forest floor will favor the germination, growth, and development of the more tolerant species; and, with the passing of time, there will be a shift in species composition so that eventually the most tolerant species will prevail. Results of field studies are showing that intolerant species have regenerated in the openings created by single-tree selection harvests, but development into the sapling and pole-sized classes is not occurring (Della-Bianca and Beck 1985; Smith and Miller 1987). The transition to tolerant species will require a rotation length or more to stabilize, and the forest manager must ensure the compatibility of the future species composition with the product objectives that have been established. If intolerant to intermediate shade tolerant species are required to meet the management objectives and an uneven-aged stand structure is dictated, then the group selection or one of the even-aged regeneration methods must be considered.

Regulation

The most difficult topic to comprehend in this discussion deals with how the forest manager ensures that the silvicultural system formulated for a particular stand will provide the development of stand structure so that long-term yields are sustained. The manager must establish and implement a means of regulating the stand, whether it be under an even-aged or an uneven-aged system.

In a stand being managed under an even-aged silvicultural system there are distinct end points that are clearly visible and easily understood. For example, when the trees in the stand reach the diameter required for the prescribed product, the entire stand is harvested and regenerated. When an intermediate operation is required, it will be evident throughout the stand and the practice will be implemented. An even-aged stand progresses through distinct developmental stages that are easily recognizable. Regulation of the stand is relatively easy and is accomplished by area control and maximum tree size.

In a stand being managed under an uneven-aged silvicultural system, regulation is much more complex. In an uneven-aged stand all developmental stages are continually present and silvicultural treatments such as harvesting, regeneration, or thinning are not separated in time. When the stand is entered at the end of the prescribed cycle, mature trees will be harvested; however, it is also necessary to accomplish the needed intermediate silvicultural treatments throughout the rest of the stand. Operations that might be included are seed bed preparation, crop-tree release, and thinning across diameter classes. Since only partial harvests are made, it is very difficult to know whether you have cut too many or too few trees. Overcutting could result in poor growing space utilization, unbalanced and poor stocking in specific diameter classes, a reduction in stem quality, and/or loss of certain desirable species. Cutting too lightly could result in insufficient space for regeneration, a reduction in individual tree growth, poor growth and development of trees in intermediate canopy positions (especially those species that are intermediate in shade tolerance) and a volume removed that is less than attractive economically. Because of the complexity of stand structure and composition, stand conditions and silvicultural practices that are obvious under even-aged systems become very obscure under an uneven-aged system. The level of professional and technical expertise required to effectively and efficiently manage uneven-aged stands is substantially greater than that required to manage even-aged stands.

A form of volume control is most often used to regulate stands being managed under uneven-aged silvicultural systems. When we look carefully at our objective of producing periodic yields of specific-sized products, some possible regulation criteria become evident. If we want trees to reach a specific size, it will be necessary to specify the diameter and then

regulate the stand so that some trees will reach the minimum product size by the end of each cutting cycle. To do this, it will be necessary to define and then implement methods to achieve a diameter distribution so that there are sufficient high-quality trees available in lower diameter classes to grow into successively higher diameter classes and eventually reach the product size. At the same time it is necessary that the stand density (basal area) be low enough so that there is room for the residual trees to grow and maintain their vigor, yet high enough so that the trees are fully utilizing the site potential. Thus, regulation in uneven-aged stands can be attained by:

1. Defining the maximum tree size (dbh) to be grown in the stand.
2. Defining a diameter distribution that reflects the desired stand structure.
3. Establishing a residual-tree basal area that will ensure individual tree growth and effectively utilize the site resources.

Maximum Tree Size (dbh)

The major factors to consider in determining the maximum tree to grow include product objective, site quality, and species. If sawtimber is the product objective, then there are factors related to tree quality and log grade that must be considered. Tree grades are used in making quality evaluations. The purpose of tree/log grades is to separate logs into several different product classes based on the relative quality of products obtained from logs with common surface characteristics. As an example, the USDA Forest Service has developed a set of hardwood log grading rules that separate logs into three quality groups that are closely correlated to lumber grade yield and gross product value when sawed into lumber (Rast et al. 1973).

The three quality classes, based on decreasing value, are grade 1 (highest), grade 2, and grade 3. It is well established that there are significant economic differences between the values of products derived from logs in grades 1, 2, and 3. The diameter of a log is a major factor in determining log grade. By allowing a tree to grow from a dbh of 13 inches to 14 inches (assuming other quality criteria have been met), the grade automatically changes from a grade-3 to a grade-2 log. It is not possible to have a grade-1 log unless the tree dbh is at least 16 inches.

Site quality affects the time required for a tree to reach a particular diameter and will affect the maximum size that a tree can attain before it starts to decline and eventually die. On a poor-quality site, certain species, such as scarlet oak or black oak, may die before they attain a diameter of 18 inches; therefore, a maximum dbh of 14 to 16 inches would be an appropriate goal. Even if the tree were capable of obtaining the diameter required for a grade-1 log, the growing conditions might be such that other quality criteria required for a grade-1 log cannot be attained.

Also, species vary in the ability to produce stems that meet the quality criteria for grade-1 or grade-2 logs. On a given site, for example, yellow-poplar is more likely to produce a high-quality log than white oak, and white oak is more likely to produce a high-quality log than is scarlet oak. White oak will produce consistently good-quality logs over a wide range of site qualities, whereas northern red oak will produce high-quality logs on good sites but stem quality will drop rather quickly as site quality declines.

On excellent sites, those with a site index (base age 50 for upland oaks) of 85 and greater, the maximum tree size goal might be as high as 32 inches. On sites with a site index of 70 to 85, the maximum tree size probably would not be set at much more than 24 to 26 inches. A maximum diameter of 14 to 18 inches would probably be appropriate for stands with a site index of 55 to 70. Species composition, individual tree quality, and economic factors are strong contributors in making the final maximum diameter decision.

When product objectives other than timber production are contemplated, the maximum tree size decision may be less important; however, the same biologic constraints related to tree growth and development must be considered.

Diameter Distribution

By establishing a specific diameter distribution goal, the forest manager helps ensure that there is a potential, through cutting or other control methods, for improving stem quality, species composition and/or spatial distribution as individual trees or groups of trees grow and move into successively higher diameter classes until the maximum tree diameter is attained.

The most often used procedure to control diameter distribution is to use the quotient between number of trees in a diameter class to the number of trees in the next lower diameter class. This quotient is referred to as a "q." It has been shown that "q" tends to be a constant over time in undisturbed, uneven-aged stands (Meyer 1952). In uneven-aged Appalachian hardwoods, the range in "q" varies from about 1.3 to 2.0 (for 2-inch diameter class increments), depending on the condition and age of the stand. A stand for which a "q" of 1.5 has been established means that if the number of trees per unit area in the 20-inch diameter class were 1, the number of trees in the 18-inch class would be 1.5 (1 x 1.5) and the number in the 16-inch class would be 2.25 (1 x 1.5 x 1.5). The graphical relationship between number of trees and diameter for three different "q's" is shown in Figure 1. The lower the "q," the smaller the difference in number of trees between diameter classes. Stands with a low "q" will have a larger proportion of the available growing space devoted to larger trees, while stands with a high "q" will have a greater proportion of the growing space devoted to smaller trees. It must be remembered that in natural uneven-aged stands the difference in number of trees between a given diameter class and the next higher diameter class will occur from competition for site resources through

natural mortality. In a managed uneven-aged stand intermediate silvicultural practices will be used to obtain the specified diameter distribution for all diameter classes below the maximum tree size. In practice, cutting will normally occur in the diameter classes where merchantable material occurs. Figure 2 illustrates where cutting could occur based on the actual diameter distribution obtained from an inventory and the diameter distribution based on the "q" established as a management goal. If there is a pulpwood market, cutting could occur in the 6-inch diameter class and above, while in regions where only sawtimber markets are available, cutting would occur in the 10-inch diameter class and above. In some stands where only sawtimber markets are available, it may be necessary to accomplish some precommercial control (either mechanical or chemical) in diameter classes under 10 inches.

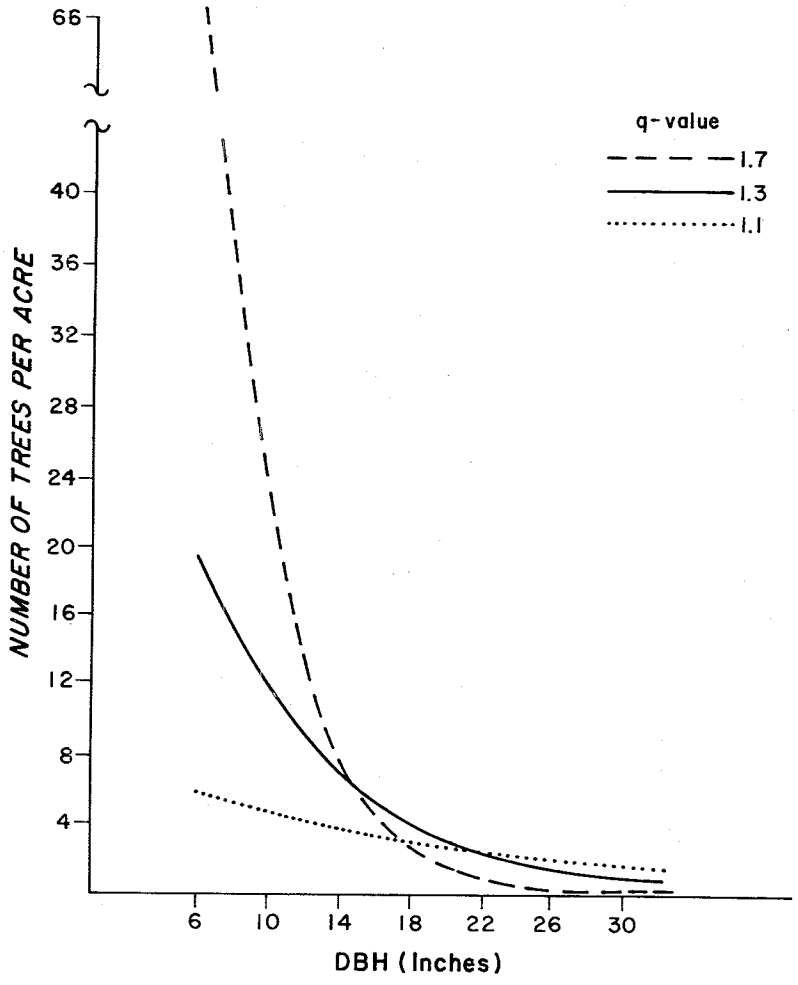

Figure 1. Stand structure curves showing number of trees per acre by dbh (2-inch classes) for three "q" values that would be common in uneven-aged Appalachian hardwood stands (Smith and Lamson 1982).

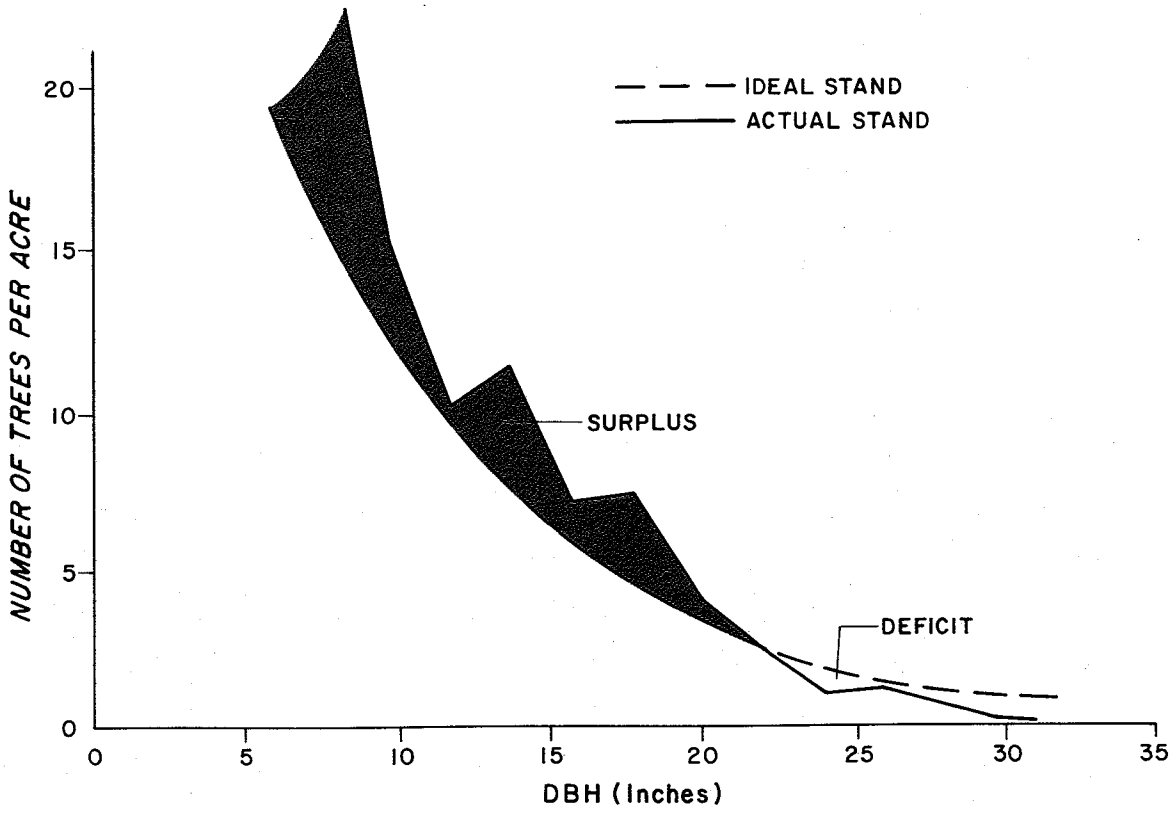

Figure 2. An illustration of where potential cutting could occur based on plots of the actual stand diameter distribution and the ideal diameter distribution based on a "q" of 1.3 for 2-inch diameter classes (Smith and Lamson 1982).

It is appropriate to consider using two different "q" values, one for the unmerchantable smaller diameter classes and one for the higher, or merchantable, diameter class. In this example, the "q" for the lower diameter classes might be 1.7 while the "q" for the merchantable diameter classes could be 1.4. By using a diameter distribution with two "q" values as just described, the diameter distribution control will be achieved; however, cutting in the smaller diameter classes will not be as intense, thus making the system more attractive economically. Similarly, the "q" can be changed as management progresses if it is shown that changing the "q" would have a management advantage or if the product objective were changed.

To minimize the potential for excess cutting when first bringing a stand under uneven-aged management it would be best to select a "q" that is closest to the actual stand structure and be within the "q" value range for the particular species group under natural conditions. As the stand responds to management and the initial structural goal is approached, the

"q" can be fine-tuned so that the specific product objectives can be more efficiently achieved.

Residual-Tree Density

There is a relatively wide range of stand densities within which stand growth varies only slightly. The upper density level for a particular species is considered to be the 100 percent stocking level, or "normal," stocking level when a relative stocking level is used. The 100 percent stocking level is based on the absolute density observed in undisturbed stands of the same type and size (Ernst and Knapp 1985). In any stand, there is a lower density limit below which stand production suffers (often referred to as the B-level of stocking) and an upper limit above which individual tree and stand vigor deteriorate (often referred to as the A-level of stocking). The density zone between the upper and lower density limit is considered the management zone (Ernst and Knapp 1985). When partial cutting is being considered, as is the case in uneven-aged stands, the goal is to keep the stand density such that stand growth is not reduced at any time during the cutting cycle. The harvesting for a particular cycle should occur prior to the time the density level is reached when total stand growth and tree vigor start to decline. The residual stand following the harvest cut should be slightly above the density level where full site occupancy is taking place, total stand growth is being reduced, and the potential for stem quality degrade from epicormic branching is minimized.

The most common absolute density measure is square feet of basal area per acre. The management-zone density is species specific and varies with diameter. As the average diameter of the stand increases, so does the absolute density as expressed in square feet of basal area. Table 1 contains a summary of the management-zone basal areas extremes (A- and B-level of stocking), by species group at three mean stand diameters. The values in Table 1 can serve as a guide for making residual-tree density and maximum density decisions in uneven-aged Appalachian hardwood stands.

Diameter-Limit Cutting

Diameter-limit cutting has been widely applied in Appalachian hardwood stands. Often the objective was to obtain a quick economic return with little or no consideration for the future stand, (and the results have been nothing more than a high-grading). When the cutting method is applied as a forest management practice, the objective is to harvest trees that are financially mature and ensure that a well-stocked stand of trees is left to occupy the site and provide for future harvests (Trimble 1971). Whether the diameter-limit cutting practice is an intermediate silvicultural technique or a regeneration method is open to question and depends on the condition, structure, and species composition of the stand following the cut.

Table 1. Summary of stocking level basal areas by mean stand diameter for species groups common in Appalachian hardwood stands.

Species group	Mean stand diameter 9 inches Stocking level [a] A	9 inches B	12 inches A	12 inches B	15 inches A	15 inches B
	Square feet per acre					
Upland oak[b]	112	65	122	71	128	74
Allegheny hardwoods[c] (% cherry, ash poplar)						
0	117	69	126	75	132	78
40	149	89	162	97	171	103
80	176	105	192	115	204	122
Cove hardwoods[d]	116	72	127	83	135	92

[a] The A-level of stocking is equivalent to 100 percent stocking and the B-level is about 55 to 65 percent of full stocking but varies among species groups.
[b] Gingrich 1967.
[c] Roach 1977.
[d] Leak et al. 1969.

The procedure for implementing the cut has been to select some lower diameter-limit and cut all stems above the limit. The diameter-limit is flexible but is usually related to a size limit for specific products. Common lower limits are 10 to 11 inches in diameter where only small sawtimber is present and 15 to 16 inches in diameter where high-quality sawtimber prevails. With the very simple diameter limit guidelines, the only advantage over a high-grading cut is that culls and undesirable species above the diameter limit are cut. The stand below the diameter limit contains both good- and poor-quality stems of desirable and undesirable species. In addition, there is no means of controlling the stocking level in the residual stand. You simply take what is left. If there are sufficient trees left below the diameter limit to provide for the future stand, then the cut may be successful from a management standpoint, provided that the species composition is acceptable. However, if there are insufficient stems remaining following the cut, new regeneration must provide the necessary stocking. Most likely the forest floor conditions would favor the more shade-tolerant species which, depending on the species,

may or may not be desirable. An improvement in the diameter-limit cutting procedure would be to include a flexible diameter limit so that there would be some control of species, quality, and spatial distribution in the residual stand. In addition, when regeneration is necessary due to poor stocking, openings of sufficient size to favor reproduction of desirable species could be provided.

The stand evaluation procedure used to set the diameter limit must be biologically sound if the procedure is being used as a management tool. The results of field studies suggest that the diameter-limit cutting procedure has the potential, under the proper conditions, of being a viable management tool (Smith and Miller 1987).

Discussion

The decision to implement an uneven-aged regeneration method requires a great deal of thought and foresight. The forest manager must be able to comprehend the stand structure and clearly understand the functioning of the stand. This decision process cannot occur without accurate and timely inventory data. The initial data must include:

1. Diameter and basal area distribution by species and some indication of spatial variability within the stand.

2. Present stem quality and the potential for quality improvement.

3. Volume of present stand and a growth rate function.

4. Age in relation to species and structural component.

5. Estimates of site quality and degree of variability within the stand.

6. Access to and within the stand.

7. Site variables that would affect the implementation of various silvicultural practices (topography, presence of streams, soil limitations, and visual limitations).

8. Present or potential insect and disease problems.

9. Factors, such as signs of intense wildlife pressure and the presence of grapevines or other nuisance plants, that have the potential for adversely affecting tree regeneration and quality aspects of the stand must be identified.

Additional inventories will be needed periodically to evaluate the effectiveness of the management procedures, ensure that the necessary stand regulation is being achieved, and make future management recommendations.

For single-tree selection, the regulation and control concepts described in the preceding sections are well documented, and after 30 to 40 years of being field tested, are producing healthy and vigorous uneven-aged hardwood stands. Management guides and application procedures for major forest types are available and in use. Most professional foresters would feel comfortable in prescribing and implementing single-tree selection techniques following a reasonable amount of study, orientation, and field practice.

The biological principles associated with the group-selection method of regeneration are sound, and the idea of increasing the size of a forest canopy opening, by harvesting more than one tree, to accommodate the regeneration of intermediate and shade-tolerant species makes sense. In reality, we are trying to obtain a biological clearcut effect but not call it clearcutting. The size of the group opening is too small to map and keep records on; therefore, the regulation and control procedures become much more complex.

It is possible for a forester to be in a stand where the single-tree selection method is being applied and visually observe a complete sample of the stand structure, from the smallest seedling to a tree of maximum diameter. The forester can compare what the stand structure actually looks like with a mental image of what the stand should look like, and then proceed to select and mark trees that should be removed from the appropriate diameter classes. In a stand being managed under the group selection method of regeneration, as a result of the size and spatial distribution of the groups, it is virtually impossible to visually observe the present stand structure. The groups (structural units) are so far apart that they cannot all be seen from any one vantage point. This inability to visualize the stand structure seriously hinders a forester's ability to provide the necessary regulation and control that is achieved through tree removal and is needed for proper management.

Point sampling inventory methods and associated microcomputer summary and display software, which will provide species, diameter, density, volume, and spatial distribution information presently are being developed. It is hoped that these tools will assist in solving the regulation and control problems associated with implementing the group-selection method of regeneration on an operational scale. At the present time, the group selection method of regeneration in Appalachian hardwoods is more of an idea than a practice.

For more detailed discussion of uneven-aged silviculture, the readers may wish to consult the USDA Forest Service Timber Management Research report issued in 1978 (USDA Forest Service 1978), review article by R.D. Nyland (1986), and textbook by D.M. Smith (1986).

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FIELD GUIDE FOR ANALYZING POTENTIAL HARDWOOD STAND REGENERATION

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ABSTRACT

Preharvest inventories of the understories of mixed oak and northern hardwood stands can give valuable insight into the adequacy of advanced hardwood regeneration, the nucleus of the next rotation. To be of value in planning the necessary cultural treatments during the regeneration period, these inventories must be carefully planned so that they provide the needed data concerning number of stems, composition, distribution and competitive ability of the desirable species.

Introduction

Many mixed oak and northern hardwood stands develop understories of woody tree species during the last two decades of the rotation. When the mature stand is harvested, this understory will form the nucleus of the new stand unless some drastic silvicultural treatment is employed to alter this successional trend. Thus some practical preharvest procedure for surveying and evaluating understories is essential for making intelligent decisions about the best regeneration method to assure a promising new stand. If the understory contains an adequate number of desirable species, it may be expedient to remove the overstory, and use this understory as the nucleus of the new stand. If, on the other hand, the understory is sparse, or is dominated by less desirable tree species, some plan for new regeneration will have to be developed prior to the harvest cutting.

Foresters should always keep in mind that many silvicultural problems encountered in managing hardwood stands originate during the regeneration period. Thus, planning and expenditures for silvicultural treatments done at this critical time will result in fewer management problems during the next rotation.

Regeneration surveys can provide the following:

1. Identify those stands where desirable hardwood mixtures will dominate the site with little or no silvicultural treatment.

2. Identify those areas that need cleanings or interplantings.

3. Identify those stands where understories, dominated by less valuable species, offer little promise and must be eradicated and replaced by more desirable hardwoods either from natural regeneration or by planting.

Too often regeneration surveys have taken the form of casual observations. The most common error is to examine only a small part of the stand, resulting in a false picture of understory conditions throughout the entire area. On the other hand, superficial observations may be all that are required in those stands where desirable understory seedlings and saplings are so abundant that systematic surveys are unnecessary.

Meaningful regeneration surveys require great familiarity with the particular hardwood forest type, and insight into the dynamics of young stand development. Some seedling- and sapling-stage tree species respond rapidly to release and dominate a site quickly, while others may not respond and will be rapidly resuppressed as other faster-growing species outgrow them. Thus a forester, when planning regeneration surveys, must know not only the best methods of sampling advanced regeneration, but also be able to make intelligent judgements on each sample plot as the field data are collected.

Identifying the Information Required

Regeneration surveys can produce various types of information. It is important to identify the information required from your survey before planning the field work. Preliminary planning will save time and money since it avoids collecting unneeded data, and assure that the time available is spent obtaining the precise information necessary for regeneration planning.

Sampling the understory for information at any particular time gives only an estimate of either the total number of seedlings and/or their distribution. Most preharvest surveys are more interested in percent stocking than in the total number of seedlings per acre, since total number of seedlings gives no information about their distribution throughout the stand.

Permanent regeneration survey plots (staked plots), however, can yield important information about changes in understory composition prior to harvesting the mature stand and changes in the new stand during the early years of development. Both one-time surveys and sequential surveys using permanent sample plots are of value.

This paper, however, discusses primarily the one-time survey that is made just prior to the regeneration period.

Survey Methods

Stocked Quadrat Method

In this survey method parallel lines are usually established at predetermined intervals throughout the stand and sample plots located at fixed distances. The location of these plots, however, may be selected at random, or if plots are taken at fixed intervals, at least the location of the first plot on each line selected at random. When an estimate of the total number of seedlings per acre, or per stand, is desired, all seedlings and saplings are tallied, usually by species. However, when the only objective is to ascertain if there is adequate well-spaced regeneration, this method of spaced plots can be used expediently by merely determining for each plot if there is a desirable seedling or sapling that is "free-to-grow".

It is possible to satisfy these two objectives simultaneously using the same plots, first for a complete tally and then checking off whether or not there is a desirable seedling, free-to-grow, present. Analysis of stocked quadrat data, as most simply applied, yields only the percent stocking.

During stocked quadrat surveys, however, it is practical to keep locations of each plot on a stand map. It is then evident from clusters of unstocked plots where areas of sparse regeneration occur. Although there have been many new and innovative regeneration field survey techniques devised, line-plot sampling using circular stocked quadrats is the oldest of the stocking survey methods. Because it is easily understood, it is still the most widely-used method. This procedure was first described by Lowdermilk (1921) and later by Haig (1931).

Distance Methods

Another method of obtaining an estimate of spacing between desirable seedlings involves randomly establishing many plot centers and measuring the distance from each center to the nearest free-to-grow seedling (Dennis 1983). The average of these distances is obtained and can be converted to an estimate of stocking per acre based on the required distances for minimum stocking.

One consideration in using both of these methods is that you obtain a stocking per acre (SPA) standard, which is the desired number of well-distributed seedlings per acre. From this, the maximum distance from the plot center to the nearest tree is derived. Seedlings and saplings that exceed this maximum distance limit are not included in the field tally (Smith 1974, Stein 1974, 1978).

Preliminary Considerations

Before sampling understory regeneration, several decisions must be made based on experience and familiarity with a particular forest type and site. The most important of these is the minimum number of well-distributed seedlings and saplings per acre that will assure an adequately stocked stand. For upland mixed oak stands I use the figure of 300 seedlings and saplings per acre. These trees must be vigorous and at least 4 feet tall. A general guide is that there should be at least four times as many desirable, free-to-grow seedlings present as the usual number of final crop trees present at the end of a sawtimber rotation on that site. This excess allows room for mortality and should permit at least one intermediate cutting during the rotation.

Correctly identifying "free-to-grow" seedlings and saplings also requires experience and familiarity with the forest type. Thus a vigorous oak seedling may be free-to-grow when of the same size or shorter than adjacent low-vigor seedlings, or shrubs that have reached full height growth. An extremely tolerant understory species, such as hemlock, may be free-to-grow even when crowded or overtopped by many shrubs or low-vigor intolerants. Assigning the free-to-grow status, thus, depends on a forester's familiarity with the dynamics of early stand development. Being able to assign this category correctly, however, is the key to meaningful percent stocking surveys.

Collecting Additional Data

In stocked quadrat surveys it is possible to categorize the dominant seedlings or saplings on each plot into groups, and record their presence with a code designation. These codes can identify whether the dominant seedling is a high-value species, an acceptable species, or an unacceptable species. For the last two categories the tally can be expanded to record if there is a smaller, higher-value species present that can be released. The value of this more elaborate stocked-quadrat tally is that it can be used to decide whether a cleaning, or crop tree release, would be of value in forming the new stand, or if a stand of merely acceptable species is the best that can be expected from a particular understory. If this additional breakdown into acceptability appears unjustified after the data are collected, all desirable and acceptable species can then be pooled into one category for an estimate of percent stocking.

Sample Plot Size

The most common error in stocked-quadrate surveys is to automatically assume that the commonly-used milacre is the best plot size to use. Plot size, however, must be determined on the basis of minimum acceptable stocking per acre (SPA). Thus, if 1,000 free-to-grow seedlings is the minimum accepted as the SPA, sample plots must be 1/1,000 of an acre in size or 43.56 square feet/seedling. Such a plot would be 6.6 feet square or 1 milacre in size. However, with today's thinking on minimum stocking in the range of 250, 300

or 400 seedlings or saplings per acre, much larger sample plots must be used (Table 1).

Table 1. Dimensions of sample plots for surveying understory regeneration based on minimum number of seedlings per acre or SPA desired.

Seedlings per acre	Square feet per seedling	Dimensions of square plot	Radius of circular plot
Number	Square feet	Feet	Feet
435	100	10 x 10	5.6
302	144	12 x 12	6.8
222	196	14 x 14	7.9
194	225	15 x 15	8.5
170	256	16 x 16	9.0
134	324	18 x 18	10.2
109	400	20 x 20	11.3
70	625	25 x 25	14.1

For a stocking of 302 seedlings per acre, each plot should be 1/302 of an acre or contain 144 square feet, thus having dimensions of a 12-foot square, or a 6.8 feet radius circle. Using smaller or larger plots than needed for these quadrat samples gives misleading results. Using smaller plots, as is so often the case since foresters have been traditionally trained to use milacres, will drastically underestimate stocking. Using larger plots gives an overestimate of percent stocking.

Table 2 contains the field data from three intensities of stocked quadrat surveys to illustrate the usefulness of the additional information gathered in Surveys 2 and 3. Survey 1 indicates only that 60 percent of the stand understory is stocked with desirable or acceptable species. Survey 2, however, gives an indication of the percent of the area stocked with desirable species, 40 percent, and that portion stocked with acceptable species, 2 percent. In addition, the survey indicates that 8 percent of the area is dominated by undesirable species and the remaining area, 32 percent, is unstocked.

Survey 3, however, gives more insight into the benefits of silvicultural treatment in this stand. By showing where plots presently dominated by acceptable or undesirable species could be upgraded by cleaning to more desirable species, an indication of the benefits of release work in this stand are clearly defined. Survey 3 indicates that by cleaning the species of trees dominating 20 percent of the stand can be greatly improved.

In addition, surveys 2 and 3 show what percent of the stand understory is lacking in tree seedlings of any type and what percent has an understory of undesirable species. This information gives insight into the benefits of interplanting in a particular stand immediately after cutting, or a clue as

to where excessive soil disturbance during logging might be beneficial by encouraging the seeding-in of intolerant species.

Table 2. Different levels of stocked-quadrat surveys giving examples of varying complexities of data that can be collected. These data were obtained from the understory of a mixed oak stand. The survey on each plot was of the seedlings and saplings that were free-to-grow. Footnotes explain each table value.

Plot No.	Survey 1	Survey 2	Survey 3
1	x	1	1
2		4	4
3	x	1	1
4	x	2	2+
5	x	1	1
6		4	4
7	x	1	1
8	x	2	2+
9	x	1	1
10		4	4
11		4	4
12	x	1	1
13	x	2	2
14	x	1	1
15		4	4
16	x	1	1
17		4	4
18	x	2	2
19	x	2	2+
20	x	1	1
21		4	4
22		3	3++
23		3	3+
24		4	4
25	x	1	1

x Indicates that a desirable or acceptable seedling occurs.
1 Indicates a desirable species--white, red or black oak.
2 Indicates an acceptable species--mockernut hickory, pignut hickory, yellow-poplar, cucumbertree, or black cherry.
3 Indicates an undesirable species--scarlet oak, blackgum, beech, red maple or striped maple.
4 Indicates that there was no tree seedling on the plot.
+ Indicates that a plot rating could be raised to the next higher class by cleaning.
++ Indicates that a plot rating could be raised two classes by cleaning.

Evaluation of Stump Sprouts

In mature stands where there are a number of overstory trees of desirable species which have the ability to produce stump sprouts, these can be included in the field tally to change the classification of a plot from that of an undesirable species or unstocked, to acceptable or desirable status. Again the evaluation of a tree as a potential sprouter requires familiarity with that particular species and its sprouting ability. Appalachian research indicates that trees of sprout origin can make up an important and valuable component of hardwood stands, and that sprouts of many species, if of low origin, will not contain butt rot or other undesirable defects (Wendel 1975; Lamson 1976).

For many years it was presumed that most tree species lost their ability to produce vigorous sprouts as they became larger, and their bark became thicker, making it difficult for dormant buds to break through. Thus, certain size limits were placed on trees that could be considered potential sources of sprouts. Wendel (1975) found, however, that most white and red oak group species in the Appalachians retained their sprouting ability, at least up through age 60, and produced vigorous, straight and promising stems destined to form an important part of the next rotation. In addition, basswood, yellow-poplar, cucumbertree, black cherry and maples retain their sprouting ability for many years. Sprouting ability did not vary with site index nor with the crown position of the tree.

When a quadrat has no desirable regeneration, the presence of a tree of known sprouting ability would justify including the anticipated sprout to upgrade the rating of that sample plot. On the other hand, if potential sprouting from an undesirable tree species is predicated, this should be taken into consideration.

Handling Fern Understories

On many of the better sites, particularly beneath cove and northern hardwood types, dense fern understories may be responsible for a lack of regeneration. It is known that intermediate cuttings increase the amount of understory fern, and thus may be responsible for a lack of advanced regeneration. Actually there are two basic groups of ferns common in stand understories--those that originate in clumps, such as the cinnamon, interrupted and wood ferns, and those that occur individually in large colonies from a vast superficial network of rhizomes. The latter group, by far the more troublesome to foresters, includes the hay-scented and New York ferns. These colony-forming ferns smother germinating tree seedlings, may mat down and crush seedlings in the autumn, and are allelopathic to certain tree species. A sparse but uniform cover of colony-forming ferns, present prior to cutting, usually indicates that a dense fern cover will become established immediately when more light reaches the forest floor.

Thus, in stocked-quadrat surveys, when plots are designated as having no woody regeneration, it would be expedient to indicate those where a dense

fern cover exists which would preclude establishing regeneration. Such information would be of use in determining where understocked parts of a stand could be disturbed during logging to facilitate seedlings establishment, and where it would be difficult to obtain regeneration.

Conclusions

Thus, pre-harvest regeneration surveys can yield important silvicultural information, pertinent for planning the regeneration method. Before initiating regeneration surveys it is essential to identify the types of stand information required to define understory conditions and potential regeneration. Collecting additional information on each sample plot may require a little more field time, and yet greatly increase the value of these data as a basis for silvicultural decisions. Conversely, collecting unnecessary data wastes time and may cloud important trends or recognizing potential problems.

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REGENERATING COVE HARDWOOD STANDS

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ABSTRACT

Cove hardwoods may be naturally regenerated by a range of harvest cutting methods. The method will succeed if: (1) the seeds, seedlings, or sproutable stems for a new stand are in place prior to harvest, (2) these stems are released from the overstory in a timely manner, and (3) competition from tolerant, noncommercial understory species is sufficiently reduced. Only a few of the commercially desirable species, mainly yellow-poplar, sweet birch, and cherry develop successfully from seed after the final harvest cut. Most other species depend heavily on advance seedlings and sprouts from small trees, which are present in many stands because of past high-grading practices. Future regeneration of mature, well-stocked stands will require more effort to develop advance reproduction by methods such as shelterwood cutting.

Introduction

The hardwood types occupying mesic sites in the Appalachians are collectively referred to as cove hardwoods or Appalachian mixed hardwoods. These stands are typically found in coves and on lower slopes with a northern or eastern aspect. The distinguishing features of these sites are the favorable moisture relations and, frequently, deep colluvial soils. Cove hardwood sites range from 65 to 90 feet or better on the oak site-index scale and from 70 to 120 or more on the yellow-poplar site-index scale.

Cove stands may be predominately one species, such as yellow-poplar or sugar maple, but species mixtures are the rule. It is not unusual to find 10 or more species in the dominant stand on an area of less than 1 acre. Other important cove species include black cherry, white ash, red maple, American beech, hickories, northern red oak, white oak, black oak, black locust, sweet birch, yellow birch, American basswood, white basswood, cucumber magnolia, black walnut, white pine, and eastern hemlock. An estimated 26 million acres of these timber types occur in the Appalachians and adjacent portions of the Allegheny and Cumberland Plateaus (Smith et al. 1983). While the cove types probably occupy less than one-quarter of the forested acreage of the Appalachians, they provide a preponderance of the high-quality sawtimber of our most valuable species.

Regenerating cove sites with trees is relatively easy. But, because the cove mixtures are complex, controlling the species composition can be a seemingly formidable task. However, there are several concepts, that, if understood and acted upon, give the forester some control over the regeneration process.

I will discuss those concepts and the actions needed to meet regeneration objectives.

Concepts

Reproductive Mechanisms

The strong reproductive potential of cove hardwoods arises from three sources:

1. New seedlings that develop from seeds in place at the time of the harvest cut or from seeds transported in from adjacent stands.
2. Seedlings that develop over a period of years prior to the harvest cut, i.e., advance seedlings.
3. Sprouts from stumps and roots of cut trees.

Regeneration of most of the cove species can come from all of the sources, but the relative importance of each source varies with species, site, and stand conditions. Table 1 outlines the primary reproductive mechanisms for some of the more important species.

Table 1. Primary regeneration mechanisms[a] for important cove hardwood species.

	Seeds	Advance seedlings	Stump sprouts	Root sprouts
Yellow-poplar	X		X	
Sweet birch	X	X		
Basswood		X	X	
Red maple	X	X	X	
Sugar maple		X		
Northern red oak		X		
Black oak		X		
White oak		X		
Chestnut oak		X		
Hickories		X		
White ash	X	X	X	
Black cherry	X	X	X	
Cucumber magnolia		X		
Black locust				X
American beech			X	X

[a]Form of regeneration at the time of the final harvest cut.

Seedling Reproduction

Only a few cove hardwood species produce a significant number of trees in the new stand from seeds that germinate after the final harvest cut. Most prominent are yellow-poplar and sweet birch, and to a lesser extent black cherry, ash, and maples. Usually no special provisions are necessary to ensure the presence of seeds. These species are consistent and prolific producers of seeds, which remain viable in the forest litter for 3 or more years (Trimble 1975). When temperature, moisture, and light conditions become favorable, the seeds can germinate, and, perhaps more important, the new seedlings can grow rapidly in height.

Stump Sprouts

Because past cutting practices often created several age classes, many stands now being regenerated contain many small trees that will sprout. In such stands, sprouts may be an important source of regeneration and are capable of producing desirable, high-quality trees. Stump sprouts, however, cannot be counted on to play a dominant role in reproducing most mature cove hardwood stands. This appraisal is based primarily on the distribution of tree sizes in fully-stocked, mature hardwood stands. While the majority of species are vigorous sprouters, the number and vigor of stump sprouts decline with increasing age and size of trees (Lamson, this proceedings; Sander et al., 1984; Wendel 1975). Sprouting is most certain from trees less than about 10 inches d.b.h. When well-managed cove hardwoods reach the size and age for felling as mature sawtimber, only 5 to 10 percent of them can be expected to produce a sprout that will become a codominant or larger stem in the new stand.

Advance Reproduction

Probably the most important source of regeneration in cove stands is advance reproductions--seedlings that are present in the understory before the harvest cut. All cove species develop to some extent from advance seedlings, even the more intolerant ones such as yellow-poplar. And for species of the intermediate tolerance, including the oaks, advance seedlings may be the primary source of reproduction in many cases. There are two important aspects to advance reproduction--its presence and its size. Advance seedlings of most cove species are present at some time, even in stands with relatively dense overstories.

Intolerants such as yellow-poplar and cherry germinate, live for several years, then die. Intermediates such as the oaks, hickories, and ash may survive for a decade or more but grow very little beneath fully stocked stands (Beck 1970; Loftis 1983). Only the most tolerant species are likely to grow to any size in the understory without substantial overstory disturbance.

Relative Tolerance of Desirables

Understanding the relative abilities of the different species to survive in the understory and to respond to release is another key to control over successfully regeneration of cove hardwoods. Spurr and Barnes (1973) define a tolerant tree as one that can survive and prosper under a forest canopy and an intolerant as one that thrives only in the main canopy or in the open. They note that many species may germinate and survive a few years in forest understories but that only tolerant species will persist and continue to grow for decades. It is also important to note that certain tolerant species not only thrive in the understory but respond to overstory removal by initiating immediate and relatively rapid growth.

Among the major Appalachian cove species, understory or shade tolerance ranges all the way from intolerant to very tolerant (Table 2). Of the species that form the dominant canopy of mature stands, however, only American beech, eastern hemlock, and sugar maple could be considered to be very tolerant. Among the important species of intermediate tolerance are the oaks, hickories, birches, and white ash. Important intolerants are black cherry, black locust, basswood, and yellow-poplar. Most intolerants and intermediates will not survive long under a dense canopy (McGee 1967). Those that do manage to survive for extended periods frequently do not respond when released.

The Nontimber Tolerant Understory

During the past half-century, fire and grazing have been excluded from most cove hardwood stands. As a result, dense understories of tolerant species have developed in these and other eastern hardwood stands (Lorimer 1984; Smith 1981). The tolerant understories may include commercial species such as sugar maple, red maple, and American beech. But more frequently they are composed of noncommercial tolerant species such as dogwood and striped maple (Table 2). In one study in the southern Appalachians, fully stocked, undisturbed stands contained an average of nearly 700 understory stems per acre 1 to 5 inches d.b.h. (Beck 1983). Some stands have as much as 35 square feet of basal area per acre in the understory. Recently disturbed stands and those with less overstory stocking may have even denser understories. What is or is not done with this tolerant understory has a large impact on the regeneration that is obtained at the time of the harvest cut.

Table 2 -Tolerance ratings[a]

Species	Tolerance rating				
	Very tolerant	Tol-erant	Inter-mediate	Intol-erant	Very in-tolerant
Eastern hophornbeam	X				
American beech	X				
Sugar maple	X				
Flowering dogwood	X				
Red maple		X			
Basswood		X			
Black gum		X			
Fraser magnolia			X		
Cucumbertree			X		
White ash			X		
Yellow birch			X		
Sweet birch			X		
White oak			X		
Northern red oak			X		
Black oak			X		
Chestnut oak			X		
Slippery elm			X		
Hickories			X		
Downy serviceberry			X		
Sourwood			X		
Scarlet oak				X	
Butternut				X	
Hickories				X	
Yellow-poplar				X	
Sassafras				X	
Black cherry				X	
Bigtooth aspen					X
Black locust					X
Pin cherry					X

[a]Trimble (1965).

Cutting Methods

In selecting a regeneration method, a realistic goal should be set for the species mixture in the new stand. One can then select a method and design its application to:

1. Have the necessary seeds, seedlings, or sproutable stems in place before removal of the old stand.
2. Reduce the competition from the dense understories of tolerant unwanted species.
3. Provide for timely release of desired species.

Given the wide range in species characteristics, it is not surprising that cove hardwoods have been regenerated by cutting practices that run the gamut from clearcutting, shelterwood, and group selection to single-tree selection. All these harvesting practices have resulted in acceptable stands under some circumstances. Species composition has been predictable only within wide limits; however, and good results often have been more attributable more to good luck than to good planning. The method most frequently recommended in the last two decades has been clearcutting. Prior to that time, single-tree selection was most widely recommended. The uneven-aged practice of group selection and the evenaged practice of shelterwood have been used and studied less but perhaps there is sufficient information to draw some conclusions about them.

Clearcutting

At one end of the harvest cutting spectrum is clearcutting. Clearcutting would be expected to result in a greater variety of species and a higher ratio of intolerant to tolerant species than other methods (McGee and Hooper 1970; Smith et al. 1983). In the southern Appalachians, cove stands on recent clearcuts are dominated by four species--yellow-poplar, sweet birch, red maple, and black locust. We expect increasing dominance by one species--yellow-poplar--as the stands develop (Beck and Hooper 1986). Stems of the first two species, yellow-poplar and birch, are largely of seedling origin. Red maple stems are primarily of stump sprout origin; because the species is tolerant, large numbers of sproutable sized maples are usually present in mature cove stands. The black locust is almost wholly of root sprout origin. At elevations of 3,500 to 4,500 feet in the southern Appalachians and at lower elevations in the central and northern Appalachians, numerous black cherry stems often appear after clearcutting. Many of these stems are new seedlings that develop after the harvest cut.

Where other species such as the oaks and ash are members of a new stand, usually their origin is traceable to sizable advance reproduction that was present at the time of the cut. Where two- and three-aged stands are

clearcut, trees of these species may be of stump sprout origin. As hardwood management intensifies, I expect sproutable stumps of oaks and other species of intermediate tolerance to become increasingly rare in mature sawtimber stands. The stands resulting from clearcutting will be dominated by species that can produce large numbers of fast-growing seedlings after the final harvest cut--most particularly yellow-poplar.

Clearcutting in coves usually includes the treatment of stems over 2 inches in diameter that are left after commercial harvest. There are numerous ways of dealing with the nonmerchantable material. Large culls can be deadened or felled. Smaller residuals can be injected or sprayed with suitable herbicides, lopped with saws or axes, or reduced by shearing in suitable terrain. In the southern Appalachians where tolerant understory species are especially bothersome, we have had good success with herbicide injection and/or basal spray of individual stems shortly before harvest (Loftis, 1985).

Shelterwood

Shelterwood cuts, with understory treatment by cutting or applying herbicide, have been used to regenerate Appalachian hardwoods. Well-stocked stands have resulted from two-cut shelterwoods with residual basal area ranging from 25 to 66 square feet per acre and overwood retained from 5 to 13 years (Loftis 1983; McGee 1975). However, species composition was essentially the same as in clearcuts with intolerant species, especially yellow-poplar dominating. Oak regeneration did not benefit from either higher residual basal area or longer periods of overstory retention. Only where large oak advance reproduction was numerous before the initial cut or sproutable stumps were present did oaks become a significant component of the new stand.

Recent studies have shown that small red oak seedlings can be nurtured to a size where they can compete after overstory removal by a modified shelterwood cut where small red oak seedlings are present, the understory species are killed with herbicides, but the overstory crown closure is kept nearly intact for 8 to 10 years (Loftis, this proceedings). We are confident that this procedure or a variation of it will work for other species of intermediate tolerance such as ash, basswood, hickory and others whose advance regeneration must be relatively large to compete successfully.

Group Selection

Group selection has not been widely practiced but there is probably enough information to piece together a picture of how it might work for cove hardwoods. Most cove species, even the intolerants, seem capable of regenerating and developing in openings of about 1/5-acre or larger. In fact, openings of 0.1- to 0.2-acre in the southern Appalachians were dominated by yellow-poplar, sweet birch, and red maple after 25 years (unpublished data, USDA Forest Service). These are the same species we

would expect in larger clearcut openings. There is no indication at present that we could expect the oaks and other difficult-to-regenerate species to fare any better under this method than any other without special provisions to develop sizeable advance reproduction.

Single-Tree Selection

Based on the species characteristics, we would expect stands managed under a single-tree selection system to eventually be dominated by tolerant species. And this has proven to be the case in actual practice (Della-Bianca and Beck 1985; Marquis 1977; Smith 1979; Trimble 1965). The result has usually been a net decrease in stand value due to lower volumes per acre and the lesser values of the tolerant species (Smith et al. 1983). The most common failing of single-tree selection is that it does not provide adequately for timely release of the intermediate and intolerant species. These species can and do become established as seedlings but are unable to develop adequately through the sapling and pole stages under this system (Della-Bianca and Beck 1985). Attempts to remove enough trees to encourage regeneration and development of the more valuable, light-demanding species poses the risk of reducing stand growth and quality through understocking (Smith et al. 1983; Trimble 1973; Della-Bianca and Beck 1985).

Summary

A broad range of regeneration practices has and will continue to be used to regenerate Appalachian cove hardwoods because of their varied characteristics and the many different objectives of ownership. Single-tree selection will be of limited use for sustained timber production because the system does not provide for timely release of intolerant species, which are the most valuable ones.

As strange as it may sound, clearcutting and group-selection are very similar biologically. Both methods provide for timely release of intolerants and for treatment of residual stems in specified areas. They both will work as long as (1) the necessary seeds or advance seedlings are in place at the time of the cut and (2) the residual stems of nontimber species over about 2 inches in diameter are treated in some way to give the desirables a chance to develop. If no provisions are made to develop advance reproduction, these practices will continue to give us stands dominated by yellow-poplar, sweet birch, and red maple in the southern Appalachians. Ash will be a component of some stands and perhaps black cherry may be a major component in the northern Appalachians and at higher elevations in the southern Appalachians.

For species such as the oaks and hickories, which have very sporadic seed crops and which develop very slowly unless given a headstart on the competition, a modified shelterwood as described by Loftis (this proceedings) is recommended to allow advance seedlings to grow large enough to compete. If seedlings of these species were not present, then a modified

shelterwood with underplanting such as suggested by Johnson et al. (1986) may be necessary. Of course, in the final analysis, before you can apply any of the ideas discussed here, you must know what you have on the ground. Perhaps the best insurance for successful regeneration is good pretreatment inventory data such as suggested by Marquis et al. (1975) and Carvell (this proceedings).

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GUIDELINES FOR REGENERATING CHERRY-MAPLE STANDS

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ABSTRACT

The major factors affecting natural regeneration in cherry-maple forests include: deer browsing, advance seedlings, interfering vegetation, seed supply, soil-site conditions, and environmental conditions as influenced by stand density and cuttings. To prescribe regeneration treatments, we recommend that these factors be assessed by collecting data on specific overstory, understory, and site variables, analyzing that data to determine the stands regeneration potential, and then deciding upon a treatment using guidelines that are based upon critical levels of the major factors. Clearcutting, shelterwood cutting, herbicide treatment of the understory, fencing, fertilization of young seedlings, and planting are all treatments that may be needed under particular circumstances. A computer program called SILVAH is available to perform the stand analysis and prepare specific presciptions for individual stands.

Introduction

Natural regeneration in the cherry-maple forest type is affected by many factors: deer browsing, advance seedlings, interfering vegetation, seed supply, soil-site conditions, and environmental conditions as influenced by stand density and cutting. Any of these factors can limit regeneration under particular circumstances, and there are many possible treatments to deal with these problems.

How do you recognize situations under which the factors cited may limit regeneration? How do you select the silvicultural treatments that will produce best results for the particular conditions in each stand?

Such silvicultural decisions can now be made in a quantitative and systematic manner. Existing knowledge and guidelines on cherry-maple forests have been incorporated into a stand analysis and prescription system, and a computer program is available to automate the process.

To use this system, you must have data on a variety of overstory, understory, and site variables that affect regeneration. These data are used to analyze stand conditions and select the most promising combination of treatments--within the owner's overall forest management objectives and economic constraints.

In this paper, I describe the major factors to be inventoried and their critical levels, and then explain how this information is used to derive a regeneration prescription.

Major Factors Affecting Regeneration

Advance Regeneration--Guidelines

Studies of the factors affecting regeneration success following clearcutting in northwestern Pennsylvania considered various attributes of the overstory and understory vegetation and soil-site factors of 65 stands prior to cutting. Examination of these stands 2, 5, 10, and 15 years after cutting revealed that advance reproduction was by far the most important of the many factors measured. Stands containing large numbers of advance seedlings had a very high probability of regeneration success, even in the presence of a large deer population, while those lacking abundant advance regeneration usually did not regenerate (Grisez and Peace 1973).

Many Allegheny hardwood stands lack advance regeneration, especially larger seedlings. Lack of seed supply, unfavorable environmental conditions due to a dense canopy, presence of interfering plants like ferns or striped maple and beech, and excessive deer browsing all contribute to this lack of advance seedlings. However, some stands contain advance seedlings, often small ones. We have developed guidelines on the numbers, size, and distribution of advance seedlings needed to provide reasonable assurance of regeneration success after overstory removal.

Stocking and number of stems. To use these guidelines, you must examine the stand being considered for harvest cutting and observe the amount of advance reproduction on a sample of at least twenty 6-foot-radius sample plots. Plots are considered stocked if they meet the criteria shown in Table 1. At least 70 percent of the plots examined must be stocked to ensure adequate numbers and distribution of advance seedlings to warrant final overstory removal (Marquis and Bjorkbom 1982).

These guidelines are based on the average numbers of stems required at various stages of the regeneration process to provide reasonable assurance that there will be at least one stem left when the new reproduction reaches poletimber (merchantable) size. For example, to end up with one pole-size stem, we estimate that there must be at least 2 saplings present after the stems grow above the reach of deer, and that this will require 5 to 25 stems during the first few years after overstory removal, and at least the minimum numbers of advance reproduction shown in Table 1.

Table 1. Minimum Number of Advance Seedlings Required for 6-foot Radius Plot

Item	Deer Impact	
	Very Low to Low	Moderate to Very High
	Number per plot	
Black Cherry		
<6 inches tall	15	25
>6 inches tall	10	17
All Desired Species		
<6 inches tall	30	100
>6 inches tall	15	15

In areas of moderate or higher deer impacts, many additional advance seedlings are required. In such areas, we attempt to provide so many seedlings that deer cannot eat all of them before some grow out of reach.

The size of plot used--6-foot radius or 1/385 acre--was selected because cherry-maple stands have about 385 trees per acre when the majority of the trees first reach merchantable (poletimber) size. Thus, having one stem on each 6-foot plot at that time assures a fully stocked stand.

Guides of this sort are much more effective than guides based on numbers of seedlings per acre, for two reasons: a) this guide assures that the seedlings are well distributed over the entire stand, since at least 70 percent of the plots must have adequate numbers, and b) it avoids giving too much weight to spots that have very high numbers of seedlings. For example, we have found that 500 seedlings per plot offer little more assurance of success than 25 seedlings--the excess seedlings simply inflate the per-acre values.

For these reasons, you cannot extrapolate the minimum numbers required per plot to per-acre values. For example, 25 black cherry per 6-foot-radius plot equal about 9,600 seedlings per acre, but we have never found a stand that qualified under the 25-per-plot rule that did not contain at least 20,000 black cherry seedlings per acre, and the average is closer to 50,000 per acre (Marquis 1987).

Size of the advance seedlings is also important. Larger seedlings have a much better chance of survival than small ones; hence, fewer are needed. For purposes of this guide, ignore advance seedlings that are less than 2 inches tall, that contain less than two full-sized leaves (indicating poor

vigor), or that are 1-year old (as indicated by presence of cotyledons). These small seedlings are not well enough established to rely on.

Seedlings over 6-inches tall and containing numerous full-size leaves have even better chances of survival than the 2- to 6-inch ones. So fewer of these larger seedlings are required. The easiest way to handle this is to give the large seedlings extra weight in advance regeneration counts. Count every two large black cherry as three stems, and every large seedling of other desirable species as two stems. Combinations of small and large seedlings are accommodated in this way (Marquis 1982).

Using this guideline, we have found that the rate of success can be raised from about 50 percent, where no attention is paid to advance reproduction, to more than 90 percent. However, many stands lack these large numbers of advance seedlings--only 38 percent of the stands in our sample contained this much advance reproduction, and evidence is increasing among agencies like the Allegheny National Forest, Pennsylvania Bureau of Forestry, International Paper Company, and Tg Forest Products that even fewer stands have adequate amounts (Brenneman 1983).

Extremely large advance reproduction of shade tolerant species may be required if these species are to secure a place in the main crown canopy of new stands containing high proportions of black cherry. Although we do not usually consider saplings and small poles to be advance reproduction, slow-growing tolerants like sugar maple may require that much head start on cherry to find a place in the main crown canopy 40 years later. This has been the case where tolerant residuals from the previous stand were left inadvertently after chemical wood clearcuts at the turn of the century (Marquis 1981a).

Where sugar maple, beech, or hemlock are desired in the new stands being created for even-age management, we recommend that 30 to 80 good quality stems of these species 3 to 10 inches dbh be retained for the next stand. Trees to be retained must be carefully selected for crown vigor and bole quality; otherwise, mortality and epicormic branching will negate the effort (Marquis 1981b). But intermediate crown-class trees that are free of epicormics before cutting tend to survive and grow well, and remain free of epicormics even when released severely.

Observations on the number of potential residuals can be made during the advance reproduction survey. Only one suitable tree per 6-foot plot is required to provide adequate stocking of residuals.

Stand Density and Cutting Methods

The seedlings beneath a forest canopy can be considered advance regeneration if even-age silviculture is being practiced, or they can be considered the new age class if uneven-age silviculture is being practiced. In either case, the degree of cutting--or the stand density--can have a major influence on the amount and size of understory regeneration present.

Numerous experiments have been conducted over the past 15 years to determine the influence of cutting methods on regeneration (Bjorkbom and Walters 1986, Husch 1954, Marquis 1979). Uncut stands have been compared to stands in which varying residual densities were created by cutting. Germination, survival, and growth were observed under these various conditions. Other studies have examined the effect of different cuttings on environmental factors such as light exposure, soil moisture, and soil temperature, and then the effects of these factors have been studied under semi-controlled conditions using shade tents, artificial irrigation, and artificially increased light levels under otherwise natural forest conditions. The effect of interrelated factors such as soil scarification associated with logging have also been examined, both in their effect on the soil environment and on regeneration establishment.

From this work we have learned that light exposure at the ground level is affected by partial cutting in a nonlinear manner. Usual residual densities left after thinning or single-tree selection cutting produce only a small increase in light exposure. To obtain 50 percent of full sunlight, for example, nearly 75 percent of the basal area must be removed. Cutting also changes the color of light available. Beneath an uncut canopy there is a very high proportion of far-red wavelengths that can inhibit seed germination or produce abnormal stem elongation in sensitive species (Marquis 1978).

Soil moisture is strongly influenced by cutting. Removal of the transpiration pump by clearcutting eliminates a major source of water loss, so the soil profile retains much more water during the growing season in a clearcut than is available beneath an uncut stand. However, the surface soil in a clearcut is exposed to direct evaporation, and the top inch or so is often very dry. This surface layer is critical for regeneration since seed germination and early development of seedling roots occurs in this zone.

Soil temperatures are also high at the surface in areas where cutting has been heavy, so the surface soil in these areas tends to be hot and dry--difficult places for seedlings to become established. Once established, however, seedling roots get down into deeper layers where moisture is abundant and temperatures are moderate. Since light is also plentiful in such areas, growth of established seedlings is rapid.

As a result of these environmental conditions, seed germination and initial seedling survival are best under moderate shade for nearly all species--even those that are light-demanding pioneers, such as pin cherry and yellow-poplar.

High survival is the key to accumulating a large number of seedlings beneath a forest canopy. Mortality tends to be high in uncut stands where light is limiting, and it is high during the first few years in clearcuts because of limited moisture at the soil surface. Best survival occurs with partial cutting. Since survival is high in partially cut stands, the numbers of

seedlings there tend to increase gradually. Where seed sources are good, the buildup can amount to many thousands of additional seedlings after 5 to 10 years (Marquis 1979). A residual relative density of about 60 percent tends to provide for the establishment of a maximum number of seedlings.

Height growth is slow under these heavy canopies. Best growth is found in full sunlight, and even moderate growth requires heavy partial cutting.

So it is possible to increase the number of seedlings beneath a forest canopy by partial cutting to leave a residual overstory density of 50 to 60 percent (Bjorkbom and Walters 1986). We can use this technique as part of a shelterwood sequence to increase the amount of advance regeneration--even for shade-intolerant species, such as black cherry and white ash.

To some extent, we can regulate species composition of the advance reproduction by varying the overstory density and the length of time that the overstory is maintained. None of the species grow fast at low light, but sugar maple does relatively better than black cherry. This is in marked contrast to their relative growth rates in the open. So to favor black cherry, the overstory should be maintained only long enough for cherry seedlings to become established. Leaving a dense overstory for a longer period will favor the more tolerant maples and beech and also seems to favor the intermediate-shade-tolerant birches. The intolerants will not survive indefinitely under a partial canopy. As the canopies begin to reclose, light levels decrease and the intolerants begin to lose vigor and die out. Our data suggest that 5 to 10 years may be the maximum time period that intolerant advance regeneration will survive, unless the canopy is very sparse. Numerous long-term studies have shown that single-tree selection cutting tends to perpetuate stands dominated by shade-tolerant species (Trimble 1965; Leak and Wilson 1958).

Interfering Vegetation

Desirable tree species are not the only kinds of vegetation that respond favorably to the environmental conditions beneath a partial canopy. Beech and striped maple are shade-tolerant trees--generally considered less desirable or undesirable for timber production--that expand after partial cutting. While intolerants like black cherry can easily outgrow beech and striped maple if both start at about the same time and grow in full sunlight, the intolerants do not fare as well when the beech and striped maple have a substantial head start (if they are sapling or larger size when the cherry starts). Dense growth of beech and striped maple may also prevent the intolerants from becoming established at all.

Ferns and grasses also expand after partial cutting, and can interfere with desirable seedlings if dense. The interference in these cases may be a combination of physical competition for light and interference through alteration of the soil chemical environment (Horsley 1977a,b,c, 1983).

Obviously, these undesirable plants must be moderately abundant before they will seriously interfere with regeneration. As we did with advance regeneration, we have developed guidelines on how much is too much. As before, we use sample plots to evaluate density. With beech and striped maple, any 6-foot-radius plot that contains eight stems total of those species is considered stocked with beech and striped maple.

With fern and grasses we do not count stems, but estimate the proportion of the ground surface covered by foliage of these plants. If 30 percent or more of the plot surface is covered, that plot is considered stocked with either fern or grass (Marquis et al. 1975). Since this evaluation is based on proportions rather than actual numbers, plot size is not critical. The 6-foot plot can be used, but a better evaluation of fern and grass is often obtained on a larger plot--such as 1/20 acre, or the area sampled by the prism.

We do not have nearly as much data on undesirable plants as we do on advance seedlings, so our guidelines on undesirable stocking are not as reliable. Nevertheless, we recommend that partial cutting be avoided in stands that have more than 30 percent of the plots stocked with any undesirable species. Partial cutting will cause rapid expansion of the undesirables where these amounts exist before cutting (Marquis et al. 1975).

In stands that are ready for final overstory removal and that have adequate advance reproduction (on at least 70 percent of the plots), larger amounts of undesirables can be tolerated. In this case, we suggest that the already established seedlings will compete effectively with the undesirable plants as long as the undesirables are present on less than 70 percent of the plots.

Where interfering plants exceed the limits mentioned above, it is often possible to control them with an herbicide applied with a skidder- or tractor-mounted mistblower. Tests of a wide range of herbicides applied at various rates and different times of the year indicate that effective control can be achieved with a combination of Roundup (glyphosate) and Oust (sulfometuron methyl). Roundup is applied at a rate of 1 quart per acre of product (1 lb ai/acre) and Oust at 2 to 4 ounces per acre of product (1.5 to- 3 oz ai/acre) in 30 gallons of water. The addition of the small quantity of Oust minimizes problems previously experienced with Roundup alone. Oust has some residual activity that eliminates areas of unkilled fern in areas traversed by the spray rig, and minimizes germination of buried grass seed in areas disturbed by logging. This application rate is effective if applied between July 1 and mid-September for fern, between August 1 and mid-September for striped maple, and between August 1 and the end of September for beech (Horsley 1981, Horsley and Bjorkbom 1982). The herbicide also kills desirable advance seedlings, but most of the undesirable plants reinvade slowly and desirable seedlings can be obtained more quickly in most cases. The herbicide should be applied immediately before the seed cut of a shelterwood sequence (Horsley 1982).

Soil-Site Factors

Although our knowledge of the specific effects of soil-site factors on regeneration success is limited, we do know that some types of sites are very difficult to regenerate.

Sites with poorly drained soils can create problems. These wet soils (which often tend to be in frost pockets as well) with restricted aeration and shallow rooting depth are inhospitable sites on which to obtain rapid growth of tree seedlings. Invasion of herbaceous plants is often rapid on these sites.

Problem sites are those with dormant-season water tables less than 6 or 8 inches below the surface. Such sites usually have very thick humus layers, may support wet-site plants, and are usually found in concave topographic positions, such as stream bottoms and depressions on the plateau top. They are also common at slope positions where water drainage from above seeps out at the surface.

Very rocky surface soils also hinder regeneration. Such sites often have a thin humus layer overlying surface rocks on a high percentage of the area. Even though advance seedlings may be present, the seedlings are often rooted only in the humus. If the canopy is removed completely, the humus is mineralized and disappears, the rocks are exposed, and the advance seedlings die. Rocky surface soils can usually be detected before cutting from the uneven surface and scattered areas of exposed rock.

We recommend that these site factors be observed during the advance regeneration and undesirable plant survey. The existence of heavy surface rock or poor soil drainage anywhere on the plot (prism plot or 1/20-acre plot) is sufficient to warrant notation. If 30 percent or more of the plots exhibit such a site limitation, special caution in regeneration practices is needed.

It is usually possible to regenerate both wet and rocky sites, but complete removal of the overstory when the advance seedlings are small should be avoided. If advance seedlings are allowed to reach sapling size before final overstory removal, they will usually have established their roots deep enough to be in mineral soil (in the case of rocky sites), or will have created enough of a transpiration pump (in the case of wet soil) to minimize the site restriction. Thus, a three-cut shelterwood is suggested: a seed cut to establish a large number of seedlings, a first-removal cut to allow the seedlings to grow to sapling size (10 to 15 feet tall), and a final removal cut to complete the harvest and release the new stand. Because it requires more cuts and the volumes to be removed each time will be less, this technique will be less profitable. Care must also be exercised at the final cut to minimize damage to the large regeneration. Windthrow is a consideration on both wet and rocky sites.

Soil scarification to provide good seedbed conditions for seed germination is relatively unimportant in Allegheny hardwoods. The primary advantage of scarified soil is that it maintains higher surface moisture than humus when exposed to direct sunlight--as in a clearcut. This is especially important for light-seeded species such as the birches, hemlock, and red maple. But in partial shade, the differences in germination among seedbeds are small, even for these species. Black cherry, sugar maple, beech, and other large seeded species germinate as well or better on undisturbed seedbeds. So we do not recommend that a special effort be devoted to seedbed scarification. This policy also avoids the risk of compaction that is associated with heavy equipment on some soils.

One last point about soils concerns the survival of advance regeneration during and after logging. Logging disturbance and soil compaction can eliminate many of the advance seedlings in areas used by skidders, resulting in patchy regeneration. Destruction of seedlings from uncontrolled skidding on vulnerable soils can easily account for failure of regeneration on up to 30 percent of an area. Disturbance also stimulates development of grass ground cover from seed buried in the forest floor. Generally, the poorer the soil drainage, the greater the number of seedlings that will be destroyed. So special care must be exercised on poorly-drained or somewhat poorly-drained soils to minimize soil compaction and loss of advance seedlings during logging. This can be accomplished by exercising control of skid trail numbers and location, by seasonal restrictions on logging, and by use of low-ground pressure logging equipment.

Seed Supply

A major factor influencing regeneration is seed supply. Through seed trapping experiments, we have learned a great deal about the periodicity of seed crops and the quantities of seeds that are produced. Black cherry and red maple produce an abundance of seeds at frequent intervals. White ash and sugar maple produce seed less frequently, and lack of seed is probably a limiting factor in regeneration of these species in many stands. Beech is the least frequent seed producer of all species studied (Bjorkbom 1979).

Many species produce seed that can lie dormant in the forest floor for several years before germinating. This greatly reduces dependence on annual seed crops and makes it unnecessary to worry about scheduling harvest cuts to coincide with bumper seed crops. Black cherry, white ash, and yellow-poplar can be stored 3 to 5 years, pin cherry for more than 20 years. Sugar maple, beech, and others do not have this capacity (Marquis 1975; Clark and Boyce 1964; Leak 1963; Wendel 1977; Auchmoody 1979).

The amount of seed produced is strongly related to the amount of basal area of that species in the overstory--if you include only basal area of those trees large enough to produce seed (8 inches dbh and greater). Regression

equations that estimate seed production have been developed for black cherry, sugar maple, and red maple. Although similar relationships undoubtedly exist for white ash, beech, and other species, we do not have enough data on these species.

Combining the seed production relationships with the advance regeneration requirements previously described, we have developed a guideline that allows estimates of seed-source adequacy based on overstory basal area. Four seed-source index values ranging from good to inadequate can be derived.

Seed production can be increased by a program of thinnings. Reducing relative stand density develops large crowns and increases individual-tree seed production appreciably. But, reducing density too much reduces the number of trees available per acre, thereby reducing total seed production. The best compromise appears to be at about 60 percent relative density. Thinning can also be used to manipulate species composition to obtain desired species of seed, and can increase seed production of species like sugar maple that are smaller than their associates by giving them room for crown expansion.

Deer Browsing

Excessive deer browsing is probably the single most important factor affecting regeneration success in Allegheny hardwood stands in Pennsylvania. Exclosures erected immediately after clearcutting and evaluated over the following 15 to 25 years have shown that about 87 percent of the clearcuts that failed to regenerate satisfactorily will produced satisfactory regeneration simply by erecting a deer-proof fence (Marquis 1981c; Marquis and Grisez 1978; Redding 1987).

Even those cutover areas that produce satisfactory numbers of seedlings can be rendered less valuable by shifts in species composition caused by browsing. Where browsing is severe, species such as beech and striped maple tend to dominate, whereas more valuable maple, ash, and yellow-poplar--species that are favored deer foods--tend to disappear. Height growth is also reduced by browsing, causing delays in establishment and longer rotations (Marquis and Brenneman 1981).

In many Pennsylvania cherry-maple stands, successful regeneration is almost entirely black cherry. While cherry is the most valuable species, cherry monocultures are undesirable. They provide no protection against fluctuations in consumer furniture preferences, and the potential for disaster from insect or disease epidemics is high. Recent outbreaks of the cherry scallop-shell moth (Calocalpe undulata (L.)) with subsequent cherry growth loss and mortality underscore this concern. Furthermore, cherry monocultures may be damaging to wildlife, which depend upon a variety of seed, fruits, food, and habitat conditions. Studies have shown that deer cannot survive on a diet of a single species. So even deer will eventually suffer from the monoculture they are creating.

In the West Virginia, Maryland, and New York sections of the cherry-maple range, deer browsing is less damaging. Deer populations have been lower in these states than in Pennsylvania, although deer numbers are currently on the rise in some places. Even so, the lush understories still present in most of these states absorb much of the impact of deer browsing. So even moderately high deer numbers may not cause excessive damage to seedling regeneration because of the abundance of available foods. Farmlands adjacent to forests can similarly reduce deer browsing impacts.

To prescribe regeneration treatments in the cherry-maple type, it is important to know how much damage deer may cause. An index to deer impact can be derived in several ways.

Deer impact should be based upon the area immediately surrounding the stands to be regenerated. Because deer live most of their lives within a small home range, I suggest using an area of about 2 square miles (1,000 to 1,500 acres, or a circle of 0.75 mile radius) on which to make the assessment.

Plot the deer population and the deer food availablity for that area on Figure 1, and read the deer impact on the right axis. The expected effect of that deer impact level on tree regeneration can be read from the left axis.

Ideally, deer population estimates are obtained for the specific 2 square mile area in question using a pellet count survey or similar deer censusing technique. But this is seldom practical, except perhaps to establish baseline population estimates for a few areas. Usually, the estimate will have to come from a much wider geographic area, such as a county or game management unit. The state game agencies can usually provide such estimates. You may need to modify their estimates based upon a one-time pellet-count survey, or by your subjective estimates of local hunting pressures and/or population numbers. This is a weak link in the deer impact determination, but research now underway may provide better techniques in the future.

The second value to be used in Figure 1, deer food availability, must also be estimated. Again, there are several ways in which this can be done. Ideally, the amount of deer food is estimated from inventories of the understory vegetation in all stands in the 2 square mile area. Such estimates can be made from the simple understory cruise that is used to assess regeneration conditions. Estimates of understory density or stocking are converted to weight of deer food through regression equations, summed across all stands, and the total used in Figure 1.

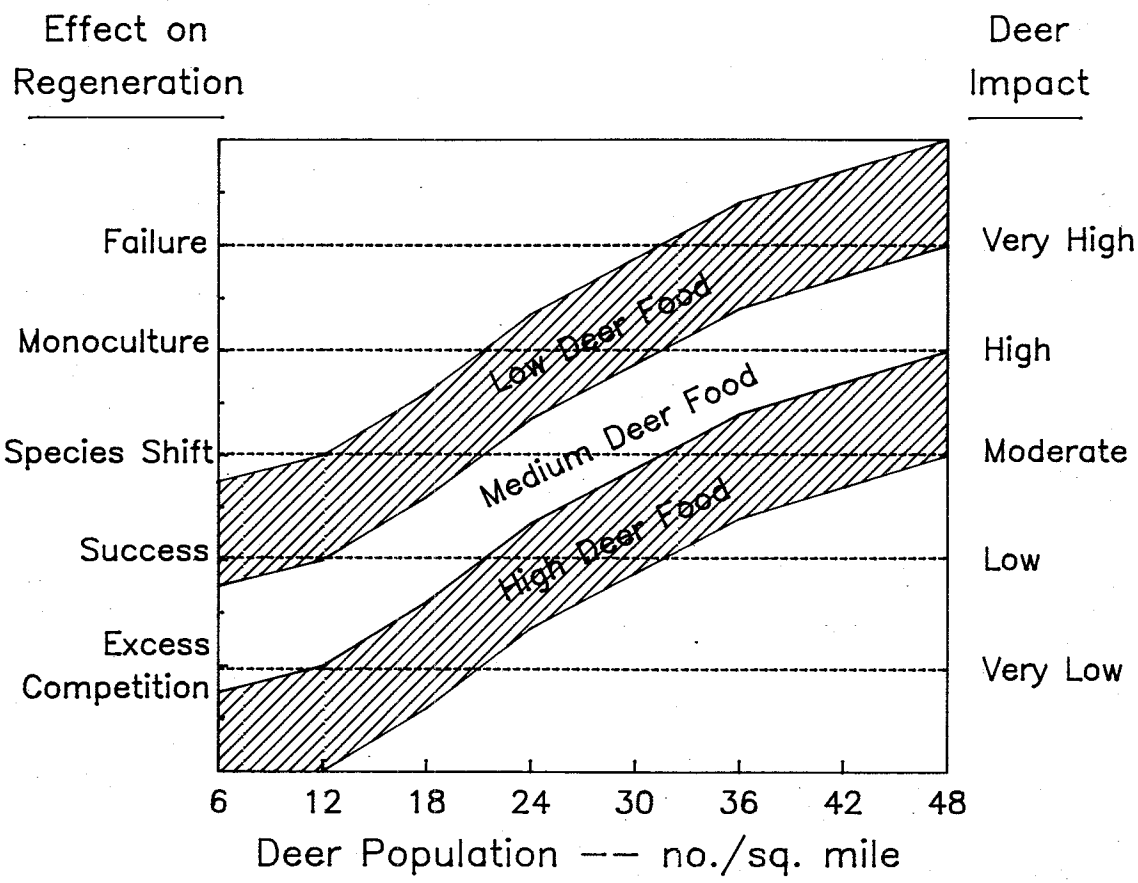

Figure 1. Deer impact on tree regeneration.

Where understory data is not available for some or all stands in the area, a crude estimate can be made from the general forest condition class (seedling, sapling, pole, unthinned sawtimber, thinned sawtimber, cultivated, pasture, etc.). Average weight of deer food in cherry-maple forests of each forest condition class are used in place of the weights calculated from the understory vegetation data and regression equations.

While these estimates may seem time consuming and cumbersome, it is not necessary to go through this process for every stand. One estimate for a compartment-size area will suffice for all stands in that area. And just a few estimates of this type will often suffice for all areas normally encountered in the management of a national or state forest, a forest industry's holdings, or the area serviced by one consulting firm or service forestry office. Even if subjective judgements must be made for both deer population and deer food availability, such estimates are better than ignoring the possible impact of deer browsing.

If deer impact index is moderate or higher, special attention will be needed to obtain successful tree regeneration. The key to success in this situation is to provide so much deer food within the home range of the local deer population that deer cannot eat all of the seedlings before some grow out of reach.

In these high deer impact situations, it is especially important to ensure that advance regeneration is abundant so that there will be lots of deer food available in the regeneration area. Use of shelterwood cutting, control of interfering plants, attention to soil-site and seed supply limitations, and similar standard considerations should receive priority attention.

There are also some special techniques that can boost the overall supply of deer food in the general vicinity and take deer pressure off the regenerating seedlings.

One important technique is to maximize the amount of cutting of all kinds within the 2 square mile deer home range. It is especially important to avoid making a single small regeneration cut in the middle of a large area that has no other recent cutting. The local deer population can easily wipe out any reproduction in such a case, because there is such a small amount of food available and they concentrate on it.

But size of the individual clearcut is not particularly important. Four 25-acre clearcuts and one 100-acre clearcut produce essentially the same amount of food. Total area in harvest cuts within the home range is the important factor. For example, total deer food production in a 2 square mile area can be increased by about 15 percent by increasing the amount of clearcutting from 64 to 128 acres (increasing clearcut acreage from 5 to 10 percent of the total area), assuming average regeneration potential.

Thinnings help to increase the amount of deer food, too, thus reducing deer pressure on the seedlings in the regeneration cuts. Thinning on 192 acres (15 percent of the total home range area) in addition to the 10 percent clearcut increases deer food production another 16 percent--a total increase of over 30 percent.

So, cutting as much acreage as possible at the same time will greatly reduce the impact of deer on regeneration, and can often make the difference between success and failure.

In some situations, none of the traditional silvicultural techniques are adequate to permit successful regeneration in the face of a large deer population. Supplemental measures, such as fencing or fertilization, may be required. While these measures are expensive, they may make the difference between total failure and a fully successful new stand, or between being able to proceed with harvest cuttings and avoiding cutting entirely.

Fertilization during the second year after final harvest is an effective way to make cherry-maple regeneration grow quickly out of the reach of deer. Black cherry responds with about 4 feet of height growth during the same year that fertilizers are applied, reducing the time for establishment from 6 to 10 years to 2 or 3 years. Fertilization not only increases height growth, but it greatly increases total deer food production for a few years, reducing the damage (Auchmoody 1982). We recommend 200 pounds of N. and 100 pounds of P applied by helicopter during early June of the second year after final harvest. Seedlings must already be established at the time of fertilization, but the fertilizer will often result in successful regeneration with many fewer stems than would otherwise be required (Nelson and Auchmoody 1987).

Deer protection is another alternative. Area fencing produces the best results, but individual seedlings can be protected where small areas of inadequate regeneration are interspersed with adequate regeneration (Marquis 1977). Brenneman (1982) has described a design of electric fence that appears to work reasonably well if carefully maintained, even though such fences are not entirely deer proof. Best results are obtained by fencing at the time of the shelterwood seed cut, but fencing at final harvest will also work.

Planting or other artificial regeneration procedures also have a place where there is an inadequate seed supply of one or more desired species. Underplanting is a possibility for introducing species, such as white ash or red oak, into the mixture. And planting is probably the only way to get desired species started in old failed clearcuts where overstory seed producers are absent and buried seeds have been exhausted. At present, artificial regeneration is recommended only in these special situations because it is extremely expensive, unreliable, and generally unnecessary where care is exercised in obtaining natural regeneration. Where used, artificial regeneration must usually be accompanied by deer protection and control of interfering vegetation to be successful.

Interrelationships Among Factors

There are many interrelationships among the factors that affect regeneration. I spoke of deer browsing as it affects regeneration after clearcutting, but browsing can interact in many ways. Deer browsing occurs on understory seedlings too, often preventing development of advance regeneration in places where it would otherwise occur. The residual density of 60 percent recommended for the seed cut of a shelterwood sequence is heavier than would be recommended if deer damage was less severe. The heavy canopy minimizes seedling growth, making the seedlings less attractive to deer, thus, minimizing damage during the period when you are attempting to build large numbers of seedlings. When there are enough seedlings, the overstory is removed at once to stimulate rapid growth and overwhelm the deer (Marquis 1979). In areas of lower deer population, a residual shelterwood seed cut density of 50 percent produces better growth and longer survival of advance seedlings.

But any cutting method that requires seedlings to grow to sapling size slowly under a canopy is likely to fail where deer populations are high. Thus, three-cut shelterwoods and selection cutting methods cannot be recommended in many parts of Pennsylvania unless fencing is also utilized.

Deer, interfering plants, and seedlings interact, too. Because deer prefer species such as bramble, and since bramble can suppress the growth of ferns, deer browsing indirectly tends to increase the amount of fern and decrease the numbers of seedlings (Marquis and Grisez 1978; Horsley and Marquis 1983).

Combinations of factors are also important. In some situations, seed supplies may be adequate if deer browsing is not severe. But if deer browsing is heavy, much larger quantities of seed may be required to generate the desired amount of regeneration. We use information of this sort in evaluating regeneration possibilities. For example, the deer-impact index and the seed-source index are added to obtain an index of regeneration difficulty that evaluates the combined effect. This is helpful in predicting whether shelterwood cutting will produce the desired results.

Regeneration Analysis and Prescription

We have developed a system of stand inventory, analysis, and prescription for Allegheny hardwoods that incorporates all of the guidelines just described to decide on an appropriate regeneration method for a particular stand (Marquis et al. 1984).

An inventory is made of overstory, understory, and site factors, and these data are then analyzed to determine present stand condition, stage of maturity, need for partial cutting, need for and possible success of regeneration cuttings, etc. This analysis leads to a prescription that specifies the appropriate silvicultural treatment for the stand.

The stand inventory includes a prism count of the overstory by species and size. This count is used to estimate stand density, seed production potential, and other factors. Observations are made on possible site limitations. And the amount of advance regeneration, numbers of tolerant trees suitable for retention as residuals, amount of sapling size understory, and amount of interfering understory vegetation are recorded.

Data from the inventory are summarized and used to estimate regeneration potential and to select the best regeneration technique. The job of summarizing the data and selecting the most appropriate treatment is readily adaptable to computer processing, and a program called SILVAH is now available to do this (Marquis 1986). The computer printout includes a two-page narrative that explains present stand conditions, recommended treatment, and reasons for its selection.

One selects the best treatment, by computer or by hand, with quantified estimates from the stand inventory in combination with a set of decision tables. By matching the various stand parameters with the critical levels shown in the decision tables, you can select the treatment that is most appropriate (Tables 2, 3).

Table 2. Decision table for even-age harvest cut with normal regeneration period.

EVEN-AGE HARVEST CUTS	CLEARCUT	CLEARCUT WITH RESIDUALS	RELEASE CUTTING	2-CUT SHELTERWOOD	HERBICIDE, 2-CUT SHELTERWOOD	SHELTERWOOD WON'T WORK; CORRECT PROBLEM	
YEARS TO MATURITY OR DENSITY OF ACCEPTABLE GROWING STOCK	0 or less than 35%	0 or less than 35%	0 or less than 35%	0 or less than 35%	0 or less than 35%	0 or less than 35%	0 or less than 35%
VISUAL GOALS	0	0	0	0	0	0	0
SITE LIMITS	less than 30%	less than 30%	less than 30%	less than 30%	less than 30%	less than 30%	less than 30%
INTERFERING UNDERSTORY	less than 70%	less than 70%	--	less than 30%	30% or more	--	--
ANY REGENERATION	70% or more	50 - 70%	--	less than 70%	less than 70%	less than 70%	less than 70%
ANY REGENERATION + RESIDUALS	--	70% or more	--	less than 70%	less than 70%	less than 70%	less than 70%
SAPLING UNDERSTORY	--	--	70% or more	--	--	less than 70%	less than 70%
RELATIVE DENSITY	--	--	--	75% or more	75% or more	less than 75%	--
REGENERATION DIFFICULTY	--	--	--	less than 5	less than 5	--	5 or more

Briefly, the decisions are as follows:

1. Where even-age regeneration openings do not satisfy the visual goals for the location, all-age silviculture with regeneration of primarily tolerant species obtained at each cut is recommended. However, this strategy usually will not work where deer pressure is heavy; all-age silviculture is not recommended in areas of high deer population.

Table 3. Decision table for even-age harvest cut with extended regeneration period.

EVEN-AGE HARVEST CUTS	3-CUT SHELTERWOOD	HERBICIDE 3-CUT SHELTERWOOD	3-CUT SHELTERWOOD BUT OMIT SEED CUT	REEVALUATE YOUR OBJECTIVES	SHELTERWOOD WON'T WORK CORRECT PROBLEM	
YEARS TO MATURITY OR DENSITY OF ACCEPTABLE GROWING STOCK	0 or less than 35%	0 or less than 35%	0 or less than 35%	0 or less than 35%	0 or less than 35%	0 or less than 35%
VISUAL GOAL OR SITE LIMITS	1 or 30% or more	1 or 30% or more	1 or 30% or more	1 or 30% or more	1 or 30% or more	1 or 30% or more
DEER POPULATION	low or medium	low or medium	low or medium	high	--	--
ANY REGENERATION	less than 70%	less than 70%	--	less than 70%	less than 70%	less than 70%
RELATIVE DENSITY	75% or more	75% or more	--	less than 75%	less than 75%	--
INTERFERING UNDERSTORY	less than 30%	30% or more	--	--	--	--
REGENERATION DIFFICULTY	less than 5	less than 5	less than 5	less than 5	--	5 or more

2. Where visual goals permit, even-age silviculture is usually best for timber production. For stands under even-age management that are mature:

   a. Clearcutting is recommended where advance reproduction is adequate and interfering understory plants are not extremely dense. Overstory removal is also recommended where there is a satisfactory sapling understory.

   b. A two-cut shelterwood sequence is recommended where advance reproduction is inadequate and where interfering plants are sparse.

   c. A two-cut shelterwood preceeded by herbicide application is recommended where advance reproduction is inadequate and interfering plants are dense.

d. A three-cut shelterwood is recommended where poor soil drainage, rocky soil, or visual goals make it desirable to have extremely large advance reproduction before final overstory removal. This technique is not recommended where deer populations are high.

In all even-age techniques, retaining 30 to 80 tolerant residual stems per acre is recommended to maintain those species in the main canopy of the next stand along with faster growing intolerants.

Once the final treatment has been prescribed and the treatment applied, it is important that periodic checks be made to ensure that regeneration is developing as planned. As before, a survey of the regeneration using 6-foot-radius sample plots is recommended. In the case of even-age silviculture, the first inventory should be made about 2 years after cutting, and additional surveys should be made as indicated by the results of the first one. At this stage of development, plots are judged as having: a) 25 desirable stems per plot total; b) 5 stems over 3 feet tall; c) 2 stems over 5 feet tall. Only when at least 70 percent of the plots have 2 stems over 5 feet tall can the regeneration be considered successful. At that point, most of the regeneration will be above the reach of deer and the stand is safely established. Before that time, the average proportion of the other two stocking measures provides an indication of the probable outcome (Table 4).

Table 4. Decision table for regeneration follow-up.

Regeneration characteristic	Regeneration is successful	Re-examine in 2 years	Re-examine in 3 years	Fertilize or protect; re-examine in 2 years	Plant, fertilize and protect, re-examine in 2 years
Plots with 2 stems over 5 feet percent	70 or more	less than 70	less than 70	less than 70	less than 70
Average of plots with 5 stems over 3 feet plus plots with 25 stems total percent	--	70 or more	50 to 70	30 to 50	less than 30

If the probable outcome is not satisfactory, fertilization or fencing should be considered. If failure is apparent, planting (probably with herbicide control of herbaceous plants) might be required. Planting should almost always be used in combination with protection and fertilization.

Obviously, the costs of reclaiming failed regeneration cuts can be very high, and should be avoided. The guidelines described for advance reproduction, interfering plants, site limitations, and choice of cutting methods should minimize such failures and provide reasonable assurance of success in most situations.

Summary

I have summarized the factors important to regeneration in Allegheny hardwoods, and have presented an overview of a stand inventory, analysis and prescription procedure that can be used to determine the management strategy most appropriate for particular stand conditions. Full details of the inventory and analysis procedures are available through publications and training courses offered through the Northeastern Forest Experiment Station and the Cooperative Extension Service of The Pennsylvania State University.

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GUIDELINES FOR REGENERATING APPALACHIAN OAK STANDS

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ABSTRACT

Increasingly, oaks are being replaced by other species in the reproduction after harvesting of current oak stands because of the lack of adequate oak advance reproduction, particularly on high quality sites. On these sites, understories are generally well developed and dominated by shade tolerant species. Recommended guidelines for using clearcutting, shelterwood, and group selection cuttings to regenerate oaks are based on an evaluation of oak regeneration potential. The results of this evaluation largely determines which regeneration cutting method should be used.

Introduction

We are finding that throughout the eastern United States the oak component in new stands after harvesting of mature oak stands is not adequate to form another oak stand. In many instances, an acceptable stand is produced but with a smaller oak component than anticipated or desired.

The lack of oaks in new stands after clearcutting is related to the lack of relatively large oak advance reproduction under the old stand. The problem occurs most frequently on the best, highly productive sites that may be currently occupied by a stand containing a high proportion of high quality oaks. But why is this happening? How did the old stand come to be dominated by oaks? If there was oak advance reproduction present that became the current stand, why isn't advance reproduction more abundant and prominent now? Based on our current knowledge, we can only speculate about some possible answers.

The current mature stands probably regenerated and developed under an entirely different set of circumstances than those under which we are trying to regenerate them today. First, the available evidence suggests that the presettlement forests did not develop undisturbed. Aside from natural events, the American Indians burned the forests to keep them open and to

improve hunting. Then the early European settlers used fire to help them clear land for agricultural crops and to control the brush for pasturing livestock. These fires often escaped and burned large areas of forest.

We know the current oak stands developed after the original harvesting that was followed by frequent fires. The oaks were probably present as advance reproduction and were able to survive the frequent fires better than species such as yellow-poplar, maples, black cherry, and possibly beech. Even as the new oak stands developed, they probably burned frequently until organized fire protection began to exclude fire from our hardwood forests.

With fire exclusion came gradual changes, and today, we have areas that are ecologically different from those that existed when most of the current sawtimber size oak stands originated. Understories are generally well developed and often dominated by shade tolerant species, especially on the most productive sites. Regenerating oaks on these high quality sites is difficult. Thus, a commitment to regenerate oaks should not be made casually. The silvicultural procedures will be costly and we cannot guarantee success.

Ecological Considerations

Much of the Appalachian area is in Braun's (1950) mixed mesophytic forest region. She describes the climax forests of this region as being dominated by beech, yellow-poplar, white basswood, chestnut, sugar maple, yellow buckeye, red oak, and white oak. Also locally abundant are black cherry, cucumber magnolia, white ash, and red maple. Minor but consistent components of the stands are hickories, blackgum, and black walnut. This picture was pieced together by looking at remnants of what were presumably presettlement forests.

The oak-chestnut forest region described by Braun (1950) includes the southern Appalachians. Here the presettlement forest on slopes at moderate elevations was apparently dominated by chestnut, yellow-poplar, northern red oak, white oak, black oak, scarlet oak, basswood, buckeye, and hickories. The oaks and hickories increased with increasing elevation to about 4,500 feet. In the coves, the forest was typically a mixed mesophytic forest.

Oaks then have always been a component of Appalachian hardwood stands, but essentially pure stands probably occurred only on the drier sites such as chestnut oak ridges. Today we see that the successional trends on the higher quality sites are toward mixtures of more mesic species. Just because an oak stand currently occupies a particular site does not mean it can automatically be replaced with another oak stand. Because of the ecological processes at work, it may not be possible within practical limits to regenerate many of the current oak stands with the expectation of getting an essentially pure oak stand again.

Some Basic Principles

Research on regeneration cutting methods has developed three basic principles governing natural oak regeneration. They are:

1. Oaks grow best in even-aged stands.

2. The new stands following complete overstory removal will contain oaks in proportion to the number and size of oak reproduction present when the final harvest is made.

3. Individual advance oak reproduction stems must be large and have well-established root systems before they can compete successfully and become dominant in the new stands (Carvell 1979; Sander 1972; Sander and Clark 1971).

The oak component in the new reproduction stands is made up of old advance reproduction, which includes all stems less than 1.6 inches dbh; new sprouts that develop after harvesting from advance reproduction; and stump sprouts from cut trees larger than 1.5 inches dbh. New oak seedlings sometimes become established after the final harvest, but grow too slowly to compete successfully and usually die within a few years. The fastest growing components in the new stand will be stump sprouts and new sprouts from advance reproduction.

Evaluating Regeneration Potential

When planning regeneration harvest cuts in oak stands, the important first step is to evaluate the potential of the oak advance reproduction to replace the current stand. Oak advance reproduction differs greatly in number and size of individuals. Some of this difference can be attributed to site quality; in general, oak advance reproduction is more abundant on average to poor sites than on good sites. Size of individual stems is important because growth after final harvest is related to both stem height and basal diameter. Thus, height and basal diameter are indicators of total plant size and the potential of the root systems to support vigorous growth after overstory removal.

Assessing oak regeneration potential involves making an inventory of advance reproduction and the overstory. The advance reproduction data are used to determine the probability that a stem of a given size will attain a specified height by the time it is 5 years old. These probabilities are then adjusted to account for drop-out from mortality and suppression to age 20. Probabilities have been developed for the Ozark Forests in Missouri and are related not only to stem size, but also to aspect and slope position. For stems of equal height and basal diameter, the probabilities are highest on southeast- and northwest-facing middle slopes and lowest on lower, northeast slopes (Sander et al. 1984). The coefficients in the estimating equation apply specifically to Missouri and must be used cautiously in other areas.

The overstory inventory data are used to estimate the proportion of stumps that can be expected to produce dominant or codominant oaks at age 20. This estimate, together with the advance reproduction probabilities, is used to determine if the new stand can be expected to develop into a predominantly oak stand by age 20.

The results of the evaluation will determine to a large degree which regeneration cutting method will most likely produce the desired results. If the evaluation is not made, the results from applying any cutting method may be disappointing and will certainly be unpredictable if oaks are wanted in the new stand.

This evaluation procedure is for oaks only. The new stand will contain other species, but we do not have a procedure to estimate their contribution to future stand stocking. We can get a general idea of what the new stand composition might be by looking at the total composition of the advance reproduction and the composition of the overstory.

If yellow-poplar is an overstory component, its regeneration potential will be great. This potential exists because numerous yellow-poplar seedlings will appear after harvest from the large quantity of viable seed in the litter and humus. The primary source of reproduction of species such as white ash, black cherry, hickories, maples, elm, blackgum, dogwood, sourwood, and sassafras is advance reproduction. Like the oaks, their growth after harvest is related to their pre-harvest size; relatively large advance reproduction stems have a higher potential for competing successfully than small ones. Although we do not yet have a system for estimating success probabilities for species other than oaks, if they are present as relatively large advance reproduction, we can expect at least some of them to become a dominant component of the reproduction stand after harvest.

Regeneration Methods

Reproduction that follows clearcutting is generally a mixture of many species. Oaks are present in proportion to their size and number before cutting. Yellow-poplar seedlings are numerous, particularly on good sites. Immediately after clearcutting and for about 10 years, understory species such as dogwood, sassafras, and sourwood may appear to dominate the stand. But, by age 10 to 15 the oaks and other overstory species begin to assert dominance and the understory species begin to drop out rapidly.

If oak advance reproduction is not adequate and the stand is clearcut, the new stand will be dominated by a varying and largely unpredictable mixture of species that may include yellow-poplar, ash, sweet birch, black locust, and maples. Some oaks will probably be present (McGee and Hooper 1970; Sander and Clark 1971; Trimble 1973).

If the oak advance reproduction is small, scarce, or absent, the regeneration method most likely to produce the best results is the shelterwood method. However, the method must be tailored to produce the microenvironments required by oaks for successful seedling establishment and early seedling growth. These microenvironments are still largely unknown and are likely to differ among differing ecological regions. For example, because of the differences in the basic ecology between the Appalachians and the Ozarks, what is required in one of these areas may not be required in the other. We can make some preliminary estimates of what generally will be required based on early results from current studies of the shelterwood method and what little we know about oak seedling establishment and growth. Both overstory and understory density will have to be controlled. The overstory density that appears to be satisfactory is 60 to 70 percent stocking according to the Central Hardwood stocking guides. As a minimum, all non-oaks in the understory more than 4 to 6 feet tall should be killed. It is preferable to kill all non-oaks in the understory. Using herbicides will be the most effective way to kill the understory competition. Prescribed fire may be effective, but three or more burns at 2- to 3-year intervals may be necessary before the understory is adequately controlled. We do not know enough about how and when to use prescribed fire effectively to recommend its general use as an aid for oak regeneration now.

One of the first responses to shelterwood cutting on average to good sites even with good understory control will be the appearance of numerous yellow-poplar, sweet birch, and ash seedlings. Based on our experience in southern Indiana, these seedlings will persist and grow under 60 to 70 percent overstory stocking and will have to be killed before newly established oak seedlings can survive and grow.

Another potential problem with the shelterwood method is seed production. Oaks are cyclic acorn producers; after the insects, squirrels, deer, and turkeys get their share, less than 1 percent of the acorns produced become available for regeneration. Furthermore, unless an adequate seed crop occurs within 2 to 3 years of understory and overstory treatment, the understory vegetation may redevelop to the point where seedlings cannot be established. Understory vegetation, especially blackberries and dense herbaceous vegetation, will rapidly invade good quality sites even when the woody vegetation has been killed.

Oaks cannot be successfully perpetuated with the single-tree selection system. Harvesting single trees and cutting to achieve and maintain a specified diameter distribution create conditions more favorable for the establishment and growth of shade-tolerant species such as maples, beech, blackgum, and elm than for oaks. Oak seedlings that do become established cannot grow into the sapling and larger size classes. As the existing sapling, pole, and small sawtimber size oaks pass through succeedingly larger diameter classes and are harvested, the sapling and small tree component will become dominated by whatever shade-tolerant species are present. Eventually the entire stand will be composed of these shade-tolerant species (Della-Bianca and Beck 1985; Schlesinger 1976; Trimble 1970; Trimble 1973).

Group selection as a regeneration method for oaks is receiving increased attention. The requirements that apply to clearcutting also apply to group selection. Oak advance reproduction of adequate size and in adequate numbers must be present where openings are created. Creating an opening, even a small one of one or two tree heights in diameter, will not ensure oak reproduction. We cannot, however, consider only the regeneration method when we apply group selection. Because it is an uneven-aged system, we must also strive to achieve and maintain a balanced diameter distribution.

Past research has not addressed the difficult problem of achieving and maintaining a balanced diameter distribution when group openings are used for regeneration. Research on the effect of opening size on regeneration has demonstrated that oaks can be reproduced in small openings just as well as in large ones (Minckler and Woerheide 1965; Sander and Clark 1971; Smith 1981). However, how the reproduction in the openings eventually contributes to the overall future stand structure and how to maintain diameter distributions have not been determined.

Regeneration Guidelines

How can we successfully regenerate oaks? The answer to this question is far from complete, but we can recommend several methods based on what we do know. The important first step is to evaluate the regeneration potential. The results of this evaluation will determine which even-aged regeneration method should be used. Or, if group selection is to be used, such an evaluation can help determine where to locate groups and can provide information on which species are reproducing and how the reproduction is growing.

Even-Age Methods

Clearcutting. If the oak advance reproduction plus stump sprouting is adequate, clearcut.

When clearcutting:

1. Determine size of area to be designated as a stand. Stand size can vary but should be at least 2 acres. Stands smaller than this have a large proportion of their area in a zone around the stand border where reproduction growth will be slow because of the influence of the surrounding trees. A stand should preferably be restricted to a single condition or size class of timber and site quality. Size of the forest property will also influence stand size. In areas where deer populations are high, stand size may need to be relatively large in order to reduce the impact of browsing on reproduction growth.

2. Arrange and shape clearcuts so they mingle with uncut stands and blend into the landscape as much as possible.

3. Harvest all merchantable trees.

4. Cut or kill remaining culls and small trees larger than about 2 inches dbh. Killing the culls instead of cutting them will provide snags for nesting holes and perches for birds. Cutting some of them will provide habitat for other wildlife species such as ruffed grouse.

If the clearcut stand is on southeast or northwest middle and upper slopes, you can expect to have a stand at about age 20 that can be molded into an essentially pure oak stand by thinning. On north and east aspects and lower slopes, the stand at that age will contain other species too, but should be predominantly oaks if the oak advance reproduction was adequate.

Shelterwood. When the regeneration potential of the existing oak advance reproduction is not adequate to replace the stand, use the shelterwood method. Oak advance reproduction is most likely to be inadequate on the middle and lower north and east facing slopes, where it will be difficult to obtain oak regeneration. Costs will be high because of the intensive site preparation needed on these high quality sites.

When applying the shelterwood method:

1. Determine stand size, arrangement, and shape the same as for clearcutting.

2. Control the understory by cutting or preferably killing the non-oak species up to about 2 inches dbh that will compete with the small oaks.

3. Reduce the overstory to about 70 percent stocking. Leave the best dominant and codominant trees as uniformly spaced as possible. Kill all unmerchantable trees larger than about 2 inches dbh.

4. If possible, apply the understory and overstory treatments before seedfall in a good seed year.

5. Monitor seedling establishment and growth and make additional light cuts to keep the overstory from restricting growth. Apply additional understory control if the understory redevelops to a point where it restricts the oak reproduction growth.

6. When the regeneration potential of the oak reproduction is adequate to replace the stand, remove the remaining overstory trees in one cut.

The length of time required to establish oaks and grow them to adequate size is not yet known but will probably be 10 to 20 years or more.

Uneven-Age Methods

Single-tree selection. The establishment and development of oak regeneration is not possible using the selection cutting practice. Harvesting single trees to achieve and maintain a specific diameter distribution favor the establishment and growth of shade-tolerant species. Oak seedlings that do become established cannot grow into saplings and larger size classes.

Group selection. This method can be used to reproduce oaks satisfactorily, but the diameter of the circular openings created should not exceed 1 to 2 times the height of the surrounding dominant trees in order to maintain the uneven-age character of the stand.

When applying group selection cutting:

1. Evaluate the potential of the oak advance reproduction to fill each opening (group) created by cutting.

2. If the oak advance reproduction is adequate, harvest the merchantable trees in the group and cut or kill remaining culls and small trees as described under clearcutting.

3. If the oak advance reproduction is not adequate to fill the opening, cutting the trees to create the opening will not result in oak reproduction and the opening will be filled by whatever species is present in the understory. In this case, follow the procedure for the shelterwood method where the openings will be located. The 70 percent stocking goal may not be attainable in the small groups, so make sure seed-producing oaks are left where the groups will be located. Removing the lowerstory competition may be all that is needed to increase the amount of light reaching the forest floor. The reproduction response will be similar to the responses after clearcutting except that reproduction growth will be retarded in a large part of the opening area because of the influence of the surrounding stand.

4. Also cut trees between the groups to maintain the selected diameter distribution.

In Conclusion

We cannot guarantee that applying the above guidelines will regenerate oaks successfully in all situations. Much research still needs to be done. However, doing nothing in the current mature or nearly mature stands will not increase the chances of getting oak reproduction. On good sites in particular, regenerating oaks is a very difficult task, and applying the silvicultural procedures will be expensive.

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REGENERATING OAKS ON HIGH-QUALITY SITES, AN UPDATE

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ABSTRACT

Information is now available that allows foresters to evaluate the red oak regeneration potential in a mature stand prior to harvest. Clearcutting would be appropriate if the regeneration potential is sufficient to meet regeneration objectives. A shelterwood method is described that will increase the red oak regeneration potential of established red oak advance reproduction. More research is needed in those areas where natural establishment of new red oak seedlings under mature stands is a problem.

Introduction

Often, maintaining a component of oak is a primary regeneration objective on high-quality sites. Some may question the value to wildlife of maintaining oaks on these high quality sites since in the Appalachians oak stands on lower quality sites are usually near. But the oak timber on these higher quality sites is extremely valuable--it is here that the highest quality sawtimber is produced. Would you like to be able to cut several thousand board feet per acre of select northern red oak from your land? And, as we create sawtimber stands for the future, there is no reason to believe that the relative value of select oak is going to diminish .

My task is to discuss the problem of regenerating oaks on high-quality sites, and to offer some recommendations. As is so often the case in silvicultural research, we do not have all the answers. But I do believe some progress has been made over the past couple of decades, both in more carefully defining the problem, and in developing some promising techniques to solve the problem.

I am going to discuss the problem from a southern Appalachian perspective. And that means concentrating primarily on northern red oak because it is the most commonly oak on the high-quality sites.

The Problem

When we have harvested mature stands from areas with an oak site index greater than 70 feet at 50 years, red oak is seldom among the dominant and codominant stems in the new stand, even though it may have been an important component in the previous stand. Even when red oak is present in a new stand as a dominant or codominant, it is almost always a less important component than in the previous stand and a much smaller component than we would like (Beck and Hooper 1986). This failure to regenerate red oak has happened repeatedly in both experimental and operational clearcuts, and it has happened in shelterwood cuts where the initial cut removed a substantial amount of stand basal area (Beck and Hooper 1986; Loftis 1983a). As Beck (this proceedings) discussed, stands created by clearcutting or heavy shelterwood cuts are dominated by yellow-poplar and sweet birch of seedling and sprout origin, black locust from root sprouts, and red maple from stump sprouts.

In examining the problem more critically, the failure to regenerate red oak is clear evidence that sources of regeneration capable of competing succesfully were not present in the previous stand at the time it was harvested. As Sander (this proceedings) indicated, the sources of oak regeneration that can compete successfully after overstory removal are now known--stump sprouts and advance reproduction. While stump sprouts can be an important source of dominant and codominant stems after harvesting mixed oak stands on lower quality sites, they usually are a far less important source on higher quality sites. The reason for this difference is that the probability that an oak will produce a viable, competitive sprout decreases with increasing stem diameter. Mixed oak stands on lower quality sites frequently contain a relatively large number of oak saplings, poles, and small sawtimber. But on higher quality sites oak saplings, poles, and small sawtimber are usually scarce or absent (Loftis 1983b). Thus, on high-quality sites, we must rely on advance reproduction as the primary source of dominant and codominant stems in the next stand. Just as on lower quality sites (Sander et.al. 1984), the larger the advance reproduction on a high-quality site, the better its chance of competing successfully after a harvest cut (Loftis 1988).

So, based on what we know about the sources of future dominant and codominant stems, the failure of oak to be regenerated on a good site after harvest cutting results from too few stump sprouts and the absence of large advance reproduction.

Advance Reproduction

Since advance oak reproduction is the key to oak regeneration in the next stand, let's look at the three developmental phases of advance reproduction:

1. Establishment
2. Development
3. Growth after harvest

Odd as it may seem, I am going to discuss these in reverse order. As you will see, there are practical reasons for this order.

Growth after Harvest

In the late 1970's and again in 1984, Ivan Sander and his group at Columbia, Missouri published guidelines for evaluating the oak regeneration potential in mature Ozark oak stands (Sander et.al. 1976; Sander et.al. 1984). These guidelines allow the forester to determine if the existing population of advance oak reproduction and potential stump sprouts will result in the establishment of an acceptably stocked oak stand after an immediate clearcut. Using a similar methodology, I have developed information that will allow the forester to assess the regeneration potential of red oak advance reproduction on high-quality sites in the southern Appalachians (Loftis 1988). Both the Ozark guidelines and the southern Appalachian work are based on the relationship between size of advance oak reproduction and its performance after a harvest cut. Also, both require a preharvest inventory of advance reproduction, as well as a measure of site quality. Using these guidelines, the forester can determine before the harvest whether clearcutting is the appropriate regeneration method.

As an example, let's consider a fairly typical mature stand sampled several years ago on the Bent Creek Experimental Forest. Stand volume was about 10,000 board feet per acre, with yellow-poplar (5,000 BF/acre) and red oak (2,000 BF/acre) the most prominent species. Site index was 90 feet at 50 years for oak, and total basal area of all stems over 0.5 inches dbh was 117 square feet per acre. The size distribution of red oak on the site was:

Red oak--Saplings, Poles, and Sawtimber

Dbh	Trees/acre
17+	5
12-16	2
6-11	2
2-5	0
	9

Advance Reproduction

Basal diameter	Number/acre
0.1	1,016
0.2	453
0.3	109
	1,578

Using the information developed for predicting performance of red oak advance reproduction after harvest in the Southern Appalachians and some adapted from Sander, Johnson, and Rodgers (1984) to predict performance after harvest of stump sprouts of saplings, poles, and sawtimber, we arrive at the following:

Red oak--Saplings, Poles, and Sawtimber

Dbh	Trees/acre	Dominance probability at age 20	Predicted number at age 20
17+	5	0.12	0.6
12-16	2	0.26	0.5
6-11	2	0.34	0.7
2-5	0	0.35	0
			1.9

Red oak--Advance Reproduction

Basal Diameter	Number/acre	Dominance probability at age 20	Predicted number at age 20
0.1	1016	0.00	0
0.2	453	0.00	0
0.3	109	0.01	1.0
			1.0

If we had clearcut this stand when sampled, we would expect to have 2.9 trees per acre (1.7 from stump sprouts and 1.0 from advance reproduction) in a dominant or codominant position in the new stand at age 20. If our regeneration goal in this stand is to regenerate as much red oak in the next stand as we have in the current stand, or perhaps to increase the red oak component, the regeneration potential in the current stand is clearly inadequate.

We now have the tools for predicting, prior to harvest, the performance after harvest of the existing population of sources of regeneration. If the population is adequate to meet the forester's goals, then clearcutting is appropriate. If, however, the population falls short of the goals, then a population of sources of oak regeneration that will meet those goals must be developed, or the goals must be changed.

Development

Clearly, there is not much we can do in the last 20 years or so of a rotation to increase the regeneration potential of saplings, poles, and sawtimber---that is, to increase their numbers prior to harvest. We must try to develop a population of large red oak advance reproduction (stems having a basal diameter, at groundline, of 2.0 inches or less). When we manipulate mature stands prior to final harvest in an effort to develop advance reproduction, we usually call this effort a shelterwood method.

Before discussing the shelterwood method, let's look at the fate of red oak advance reproduction in the absence of disturbance. In the 1960's Beck (1970) established a study to examine the response of red oak advance reproduction recently established under mature stands. One treatment was no disturbance. After 12 years, survival of red oak seedlings was only 10 percent (Figure 1). More important, growth of these survivors was negligible in the absence of disturbance (Figure 2). Clearly, small red oak advance reproduction will not develop into large advance reproduction in the absence of disturbance.

The idealized shelterwood method might involve a preparatory cut to alter seedbed conditions, a seed cut to stimulate seed production of the desired species and eliminate seed production of less desirable species, one or more release cuttings to increase the size of the advance reproduction, and a final removal cut (Smith 1962). Since advance reproduction is such an important source of regeneration for oaks, a shelterwood method has always seemed to be the logical method for regenerating oaks.

Our experience with shelterwoods in the Southern Appalachians dates back 25 years. The results from our early cuts were quite consistent and provided some important direction for our more recent studies. In these early shelterwoods we learned that whenever an initial cut on a high-quality site removed 50 percent or more of total stand basal area--(0.5 inches dbh and larger) species such as yellow-poplar and sweet birch were able to become established and grow, particularly in canopy gaps. And even though established oak advance reproduction did grow, it was hopelessly overtopped by the new reproduction of yellow-poplar and sweet birch and by sprouts of shade-tolerant subcanopy species such as dogwood. Any new oak reproduction that became established after the initial cut was in an even worse competitive position (Loftis 1983a).

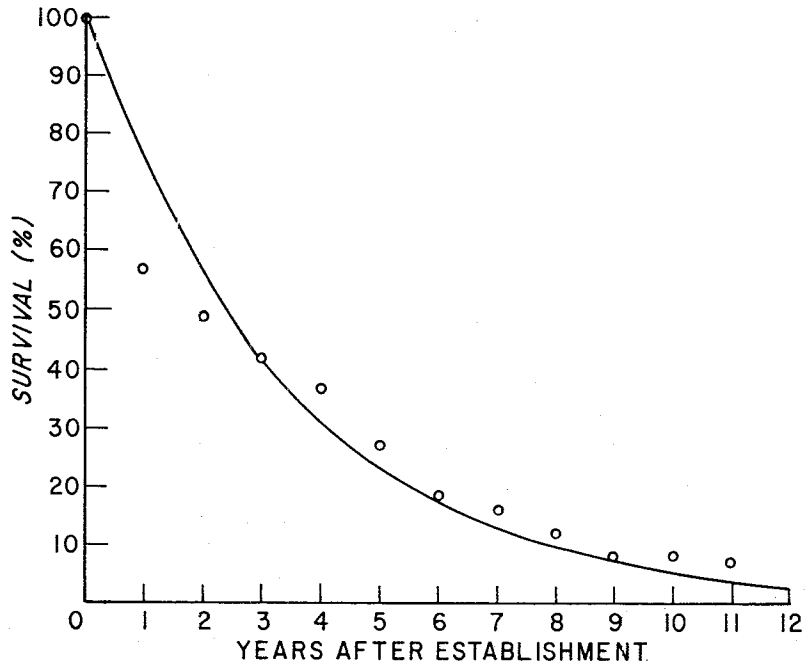

Figure 1. Survival of red oak seedlings under mature, undisturbed stands.

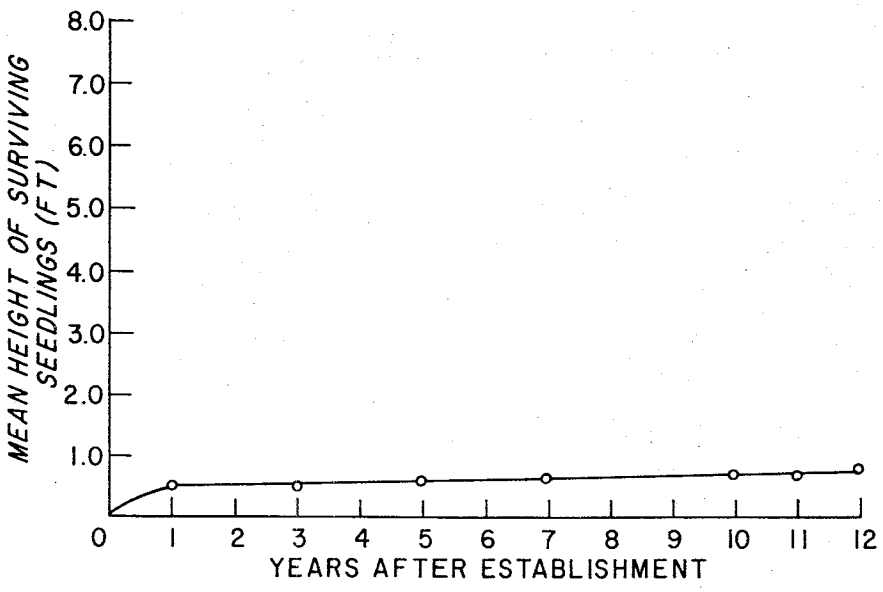

Figure 2. Growth of red oak seedlings under mature, undistrubed stands.

These results suggested that a shelterwood to regenerate oaks must allow for the growth of red oak advance reproduction without simultaneously allowing competing species to gain a competitive advantage. Ideal conditions would be:

1. A basal area reduction low enough (or a residual basal area high enough) to prevent yellow-poplar from becoming established and growing.

2. The elimination of the shade-tolerant subcanopy competition.

Ten years ago on the Bent Creek Experimental Forest and 7 years ago on the Chattahoochee National Forest in northern Georgia, studies were established to examine the response of red oak advance reproduction and associated species to levels of basal area reduction ranging from 0 to 40 percent of initial basal area, which included all stems greater that 0.5 inches dbh. In these studies basal area was reduced with herbicides, from below. That is, beginning with the 1 inch dbh class, all non-oaks in that class and successively larger diameter classes were injected until the assigned basal area reduction for that plot was accomplished. In the Georgia study I also looked at the response to prescribed fire.

After 9 and 6 years, respectively, the results of these studies are very encouraging. The single prescribed burn in this study did not produce any positive effects that would benefit oak regeneration on high-quality sites. However, we found that there is a level of basal area reduction which will 1) enhance the survival of newly established red oak seedlings (Figure 3), and 2) allow for growth of these seedlings (Figure 4), without

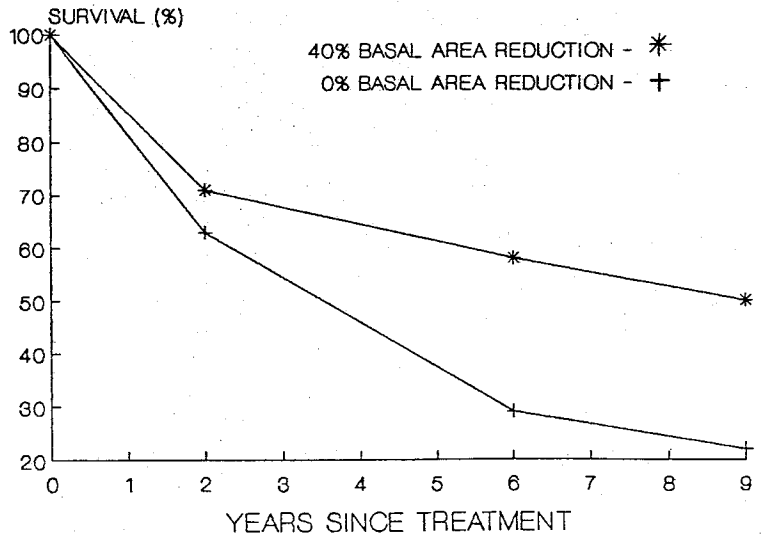

Figure 3. Survival of red oak seedlings with and without basal area reduction--Bent Creek Experimental Forest.

yellow-poplar becoming established and growing. Using herbicides to reduce basal area eliminates the competition from the shade-tolerant subcanopy species. The appropriate level of basal area reduction varies with site quality.

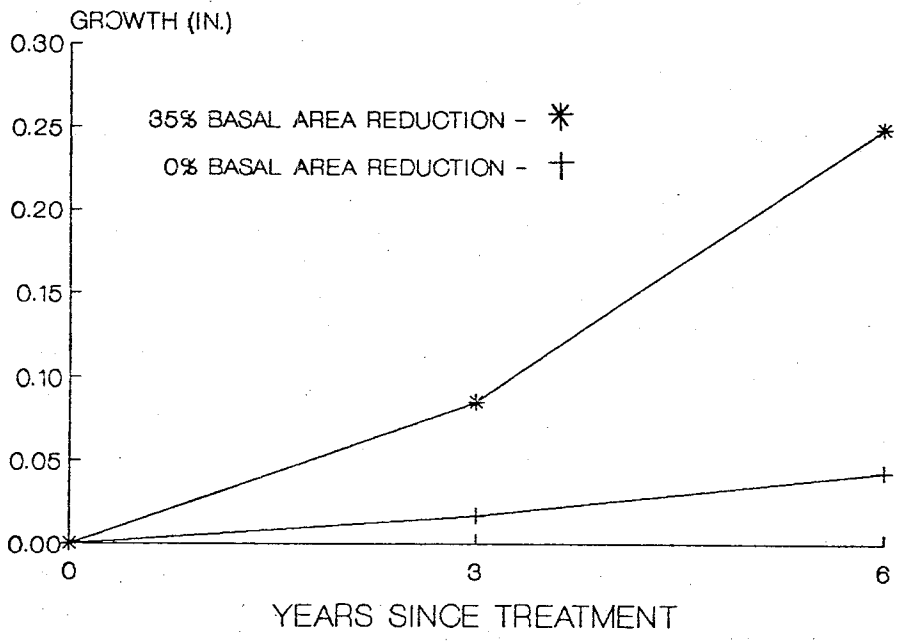

Figure 4. Growth of red oak seedlings with and without basal area reductions--Georgia.

Let's return to the example predicting the number of dominant and codominant red oak stems 20 years after clearcutting. Recall that the oak site index was 90 feet, and that the size distribution of advance red oak reproduction was as follows:

Red Oak--Advance Reproduction

BASAL DIAMETER	NUMBER/ACRE
0.1	1,016
0.2	453
0.3	109
	1,578

This population of advance red oak reproduction would contribute only one dominant-codominant stem to the next stand if the stand were clearcut at that time. Based on the recent shelterwood research results, I reduced stand basal area by about 30 percent. This treatment eliminated the subcanopy and a few trees in the lower canopy. The residual stand contained

about 80 square feet of basal area per acre with no gaps in the canopy--a condition I have heard described as a "high shade". Four years after treatment the size distribution of advance red oak reproduction has changed dramatically:

BASAL DIAMETER	NUMBER/ACRE
0.1	94
0.2	406
0.3	375
0.4	156
0.5	94
0.6	16
	1,141

Over 70 percent of the initial population of red oak advance reproduction has survived. If the dominance probabilities are applied to this current distribution, one would expect 7.7 trees per acre to be contributed to the next stand if the overstory were removed at this time. The chances of maintaining a red oak component on this site in the next stand are much better than they were 4 years ago. And based on the trends observed on the research plots, the contribution of the advance red oak reproduction will be increased to about 17 trees per acre if the overwood is left in place for another 4 to 6 years.

The shelterwood method described above is based on developing a population of large advance reproduction from a population of advance red oak reproduction which is already established on a site. I have seen no evidence in my studies, or in our earlier shelterwood studies, that the type of stand disturbance I have described will result in the establishment of new seedlings. In the terminology of the shelterwood method, the treatment described above should be considered a partial removal cut to strengthen advance reproduction. The preparatory and seed cuts of the idealized shelterwood method are not part of the method I have devised.

Establishment

Fortunately, on high-quality sites in the southern Appalachians, establishment of new seedlings is seldom a problem. We routinely find 1000 or more small red oak seedlings under mature stands. And after a bumper red oak acorn crop, which occurs once or twice every decade, new seedlings are particularly abundant. Sometimes, the claim that a stand lacks any advance oak reproduction results from casual observation rather than from sample data. Often, these observations are made in the dormant season when small oak advance reproduction is very difficult to see.

There are, of course, stands with little or no advance oak reproduction. From my conversations with other foresters, this lack of advance oak reproduction appears to be much more common in the central hardwood region and the Northeast than in the southern Appalachians. Johnson et al.(1986) have shown that foresters can plant and develop advance oak reproduction in

the Ozarks. This method may have broad application beyond the Ozarks. But, with regard to treatments that will enhance the natural establishment of new oak seedlings, I plead ignorance. The effects of large deer herds or a thick, snow-pack litter on oak seedling establishment are factors that we simply have not dealt with in the southern Appalachians.

Summary and Recommendations

If one has a goal of regenerating a red oak component on a site that now supports a mature stand, the first step is to assess the red oak regeneration potential of the current stand. The current size distribution of red oak on the site, from mature trees to small seedlings, must be determined by sampling. We now have the information that will allow foresters, based on this sample, to predict, prior to harvest, the expected contribution to the next stand of both an existing population of advance red oak reproduction and stump sprouts in the event of an immediate clearcut. If the current regeneration potential is sufficient to meet regeneration goals, the mature stand can be clearcut.

If, however, the regeneration potential is not sufficient to meet the goal, we have devised a regeneration method that will enhance the growth of an existing population of small advance red oak reproduction. This regeneration method would create a population of larger advance red oak reproduction that can contribute dominant or codominant stems to the next stand. This method consists of:

1. Eliminating, from below, 30 to 40 percent of initial stand basal area with herbicides, leaving the main canopy intact.

2. Removing the main canopy 8 to 10 years later.

In practical application, it may only be necessary to treat stems 2 inches d.b.h. and larger in many cases. But when large numbers of stems of species such as striped maple or silverbell are present, it would be wise to treat even smaller sized stems. The herbicide treatment can be accomplished with either cut-surface treatments (hack-and-squirt or injection) or with a combination of cut-surface for stems larger than 3 inches d.b.h. and thinline stem treatment for smaller stems. The most recent National Forest contracts for this type of treatment are in the $50 to $60 range, including chemical. I should also point out that, using this method, there will be little or no need for control of residual vegetation, since it is the vegetation that would normally be residual that is treated with herbicides.

This research was done in the southern Appalachians on high-quality sites where there are no apparent problems establishing red oak seedlings, and where small red oak seedlings are usually present under mature stands. Where there are establishment problems, more research is needed. But once new seedlings are established, I believe the suggested shelterwood method, perhaps with some modifications, will result in the development of large advance red oak reproduction.

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SHELTERWOOD CUTTING TO REGENERATE OAKS--THE GLATFELTER EXPERIENCE

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ABSTRACT

The Glatfelter Company has been successful in regenerating oaks through the shelterwood system on Company and privately owned properties in south central Pennsylvania. Successful implementation requires attention to time, place, and technique. Deer and undesirable understory vegetation are the primary causes of failure. Periodic control of gypsy moth defoliation is a requisite if application of the shelterwood system is to lead to desirable regeneration. In order to put the shelterwood system into practice the forester will be required to educate both the landowner and the logger.

Introduction

For the past 10 years, The Glatfelter Pulp Wood Company has been using a two-cut shelterwood system to reproduce oak-hickory and oak-white pine stands on Company and privately owned woodlands in south central Pennsylvania. I will try to present some of the very basic things we have learned to do and not to do over that period of time.

At the onset, we need to understand what we are supposed to accomplish with our shelterwood cut, namely, the regeneration of the stand by seedling or seedling-sprouts. We are aware that some stumps will sprout and these sprouts may be part of the future stand. But by design, in the shelterwood system, the sprouts are not meant to constitute the bulk of regeneration.

Regeneration Considerations

Regeneration of oaks and associated species can be described as a combination of the proper technique at the proper time and in the proper place. All this tempered with a good dose of patience. Results take time.

Proper place. We'll deal with each of these items in reverse order. First, we will consider place. Since in almost every case we want oak to be a sizeable portion of the regeneration, it is necessary to have a nearly fully stocked stand with sufficient seed producing oaks to provide acorns for establishment of the new stand. No oak trees! No acorns! No regeneration! New plan! In such a situation, the only way to ensure oaks in the future stand is through planting. The stand must be nearly fully stocked in order to have sufficient volume to allow a cutter to profitably work through the stand twice in a 5- to 10-year period. No profit! No cutter! No management! It's as simple as that.

A second requirement of place is a stand whose oak site index is between 55 and 75, sites whose SCS (Soil Conservation Service) classification is fair or good. This is the area where oaks are most likely to respond to or need a shelterwood harvest. On sites less than 55, if there are oaks in the overstory, there will likely be oak regeneration no matter what the forester does; clearcut, selection, or shelterwood. Also, on these sites there may be insufficient volume to justify the two cuts within a 5- to 10-year period. On sites above 75, maintenance of oaks as a major component of the stand requires extra effort and planning--even to the point of eliminating already established desirable reproduction. The Glatfelter Company has not gone to such lengths, we have only tried to create the most favorable conditions for oak reproduction to develop. Fortunately, other desirable species will respond well to the shelterwood system (yellow-poplar, sugar maple, white pine) and by using the shelterwood we may be able to maintain or increase the oak component.

The third aspect of place is terrain. As I have said, it is necessary to make two trips onto the site in order to develop and release regeneration through the shelterwood system. It is also necessary to be able to physically maneuver equipment and the material to be removed around the residual trees. The most serious of the limitations is slope. Sometimes it is physically impossible, with equipment generally available, to make a partial cut without completely ruining the residual stand. Foresters have to recognize the fact that sometimes on certain sites it is impossible to institute a management plan based on sound silviculture. These are areas that we should walk away from and reexamine in 10, 20, or 30 years when stand conditions and harvesting equipment have changed.

Proper time. The second consideration is time, time as in the age of the stand and time in relation to acorn crops.

Since we have agreed regeneration is to be composed primarily of seedlings or seedling sprouts, the desirable oaks in our stand must be capable of producing enough acorns for the weevils and wildlife in addition to those needed for regeneration. Generally in a fully stocked oak stand this will begin to happen at about age 55. Consequently, age 55 would appear to be the lower limit at which a shelterwood cut should be considered. However,

for another reason, this may be too young. Oaks at this age are generally vigorous sprouters. If the forester's desire is to improve the genetic composition of the stand by eliminating the less desirable stems, allowing the "superior" trees to reproduce the area, a delay of some years will be required.

In terms of numbers of stems of "desirable" reproduction or percent of area stocked with "desirable" reproduction at age 55, a combination of seedling, seedling sprouts, and sprouts certainly will be adequate. The definition of "desirable" in this case is based on species only and not on the quality of the individual stems within the species. The older the stand the more opportunity to eliminate "undesirable" genotypes of a species and build up a reservoir of advanced regeneration prior to the time of harvest. At some point the landowner must make a decision. This decision is based on the scientific information presented to him by the forester and ownership objectives--now is the time to reproduce the stand.

The second time consideration is time in relation to seed fall. Our best results have occurred when the initial shelterwood cut was completed within 3 years of a bumper seed crop. The statement may seem to be contradictory since the shelterwood cut is viewed as reproducing the stand provided by seed from the residual trees. This will happen if a good acorn crop occurs within 3 years of the initial cut. If seed fall occurs under a full canopy before the shelterwood cut, seedling numbers drop off dramatically after 3 years from time of sprouting. If there is a good seed crop and it is more than 3 years after the cut, competing vegetation, woody and herbaceous, will effectively suppress newly sprouted seedlings. The degree of competition presented by this developing layer must be evaluated yearly. If control becomes necessary, it like the shelterwood cut, should be timed to coincide with a good acorn crop.

Traditionally, we have emphasized the seed producing nature of the shelterwood system over the sheltering aspects of the residual stand. In the long run, it may be that the sheltering is as critical or more critical to the development of regeneration of desired species as is the seed production aspect. In our experience, the presence of an overstory of proper density tends to hold back development of herbaceous competition as well as undesirable woody vegetation. It also appears as if desirable seedlings browsed by deer tend to recover more rapidly or at least compete more effectively with other vegetation in a shelterwood stand than they do in either a clearcut or uncut stand.

Understand, I realize a program basing cutting schedules on time of acorn production plays havoc with a uniform yearly flow of forest products and annual cutting budgets. However, if oak regeneration is the overriding concern, some adjustments and tolerance of fluctuations in the rates of production will be necessary, particularly in the early stages of adoption of a shelterwood system of regeneration. Once into the program initial cuts can be emphasized during the periods of seed fall and final removals during

those years lacking sufficient acorn crops. By doing this, the flow of forest products can be kept relatively constant. For those who work with private landowners, this need to delay can be particularly troublesome. Usually when these individuals decide to cut timber, an operation they equate with forest management, they want to do it right now! No delay! It takes a lot of explaining to convince them a delay is in their best interest. Sometimes it cannot be done.

Proper technique. I will briefly explain our technique for handling a shelterwood cut.

First, marking is generally "mark to leave" rather than "mark to take." "Marking to leave" places emphasis on the trees to leave in terms of quality and spacing and results in a more uniformly spaced stand than "marking to take." Trees to leave are taken from the dominant crown class with an occasional codominant in cases where no desirable dominant can be found. By selecting from these crown classes and discriminating against trees which show a tendency toward epicormic branching, epicormic branching on the residual stems is minimized.

Originally, we attempted to develop a 50 percent crown cover. Reviewing results of the early cutting has led to the feeling that 55 to 60 percent crown cover will be more favorable to the oaks at the expense of the more tolerant red maple and black birch. "Marking to leave" based on crown cover does change the mechanics of timber marking. The marker is forced to look higher into the trees constantly evaluating crown size and distance between crowns. It is difficult to translate basal area into crown cover since basal area required for any degree of crown closure will vary depending on diameter of the trees, site index, individual tree characteristics, and stocking. Consequently, there is no choice but to pick a leave tree on the basis of the distance of its crown from the crowns of other potential leave trees rather than the basal area of that particular location.

If competition is expected from an undesirable understory, it is chemically treated prior to harvest. Individual stem treatment is the rule, using a hypo-hatchet or basal spray, depending on the stem diameter. About 1 inch dbh is the break point. We have not gone to broadcast applications of Roundup or similar chemicals, as is being done in the northern hardwood stands, because to this point we have felt we needed to preserve any oak seedling which might be in place. We are toying with the idea of trying an application of this type if we get a good acorn crop in a stand where regeneration has been slow to develop.

All stems 2 inches dbh and larger are felled as part of the harvesting operation. We sometimes raise this level to 4 inches dbh if there are overwhelming numbers of stems between 2 and 4 inches dbh which have been treated. "Marking to leave" simplifies this operation also since the cutter knows to cut any unmarked trees above a certain diameter. There is no question of what is to go or what is to stay.

Regeneration Evaluations

Regeneration evaluation begins 5 years after the initial cut. Final overstory removal takes place when at least 70 percent of the milacre plots are stocked with a desirable seedling greater than 2 feet in height. Two feet is the minimum acceptable height and if all reproduction barely exceeds that figure, the final harvest is delayed for a year or more to allow for additional height growth.

Most of our overstory removal will take place 5 to 10 years after the initial cut. Final overstory removal can be delayed for several years after regeneration establishment but if delayed too long, unnecessary damage to the regeneration may result. In addition allowing the regeneration to reach heights of 10 to 15 feet creates problems for the harvesting crews. Costs of production go up and the thick brush increases the possibility of accidents while limbing and topping.

A side benefit of our use of the shelterwood system has been our ability to concentrate 5 to 10 years of growth potential on high quality stems. Since most of the trees selected to remain are from the dominant crown class, they respond well to the availability of extra sunlight, water, and nutrients, sometimes doubling the diameter growth of the previous time period.

The following illustrates the difficulty in projecting oak reproduction (Table 1). These two research plots 1/40-acre in size were established in a stand which received a shelterwood cut in 1974, and had the overstory removed in 1984. At intervals over the years, we have attempted to take a 100 percent inventory of the reproduction in those plots. They were located within 200 yards of each other. One, the lower plot, was located under a primarily white oak overstory while the upper plot was in an area dominated by red oak and chestnut oak. At this point the composition of the reproduction is very different.

Here is a case of almost identical treatment being applied at the same time but with very different results. In the upper plot, oak will make up a significant portion of the future stand. In the lower, without additional work, oak may be only a minor component.

Shown below are summaries of reproduction just prior to overstory removal in stands which had received an initial shelterwood cut (Table 2).

Table 1. Periodic regeneration stem counts for a two-cut shelterwood stand--T-810 Washabaugh Reproduction Plots

Plot	Species	Height	Stems per acre prior to growing season 1976	1978	1980	1983	1987
		-Feet-	----------Number----------				
(Upper)	Ash, Y-P	<4'	7,000	6,200	8,000	1,800	1,100
		>4'	--	--	--	400	200
	Oak-Hick.	<4'	7,200	6,600	6,800	2,200	6,200
		>4'	--	--	--	3,800	2,400
	Other Sp.	<4'	6,400	6,800	9,000	3,200	2,800
		>4'	--	--	--	1,600	5,000
(Lower)	Ash, Y-P	<4'	10,200	11,200	12,000	7,400	2,800
		>4'	--	--	--	1,200	600
	Oak-Hick.	<4'	1,000	3,000	800	600	1,000
		>4'	--	--	--	--	400
	Other Sp.	<4'	7,800	9,000	10,900	3,200	2,200
		>4'	--	--	--	8,600	6,000

The numbers on the foregoing chart shows that we have been able to develop a sizeable oak component in the regeneration of stands where we have used the shelterwood system. This has been done in stands which have been infested with gypsy moth. However, to do so has required the stands to be sprayed periodically at 2- to 5-year intervals during the critical periods of the cycle. If a landowner is not going to make a commitment to control gypsy moth caterpillars at critical times in the life of the stand, the landowner will have little or no control over the development of regeneration and the composition of the future forest. A landowner will be relegated to the role of salvager of dead material or liquidator of merchantable volume before the infestation arrives.

Table 2. Reproduction summaries of five stands before the final overstory removal cut.

Tract	Height	803	847	859	872	879
	-Feet-	Percent of milacre plots stocked[a/]				
Years between cuts		4	3	5	7	7
Species						
RO[b/]	<2'	4	5	-	-	-
	2-4'	31	23	3	16	8
	>4'	4	5	6	16	22
WO[c/]	<2'	-	-	3	-	-
	2-4'	4	18	5	-	5
	>4'	12	-	8	27	10
Total oak		55	51	25	59	45
WP[d/]	<2'	-	-	5	-	-
	2-4'	-	-	6	-	-
	>4'	-	-	32	-	-
Ash/Y.P.[e/]	<2'	4	9	-	-	-
	2-4'	-	23	3	-	2
	>4'	19	-	9	-	36
Total all desirables		78	83	80	59	83
Other[f]	<2'	-	-	-	-	-
	2-4'	-	-	-	-	-
	>4'	12	9	17	40	10
Total tree species		90	92	97	99	93
Oak site index		65	60	55	65	60

a/ Counting the most desirable seedling reasonably free to grow.
b/ Red oak family.
c/ White oak family.
d/ Includes all conifers.
e/ Includes hickory and sugar maple.
f/ Other tree species including red maple, black cherry, and black locust.

Regeneration Problem Areas

Where there have been failures, and there have been a few stands where we have not been able to develop adequate regeneration, the failure has been attributed to two causes--uncontrolled undesirable understory and browsing of white-tailed deer. We have become more adept at identifying potential undesirable understory problems and have not had recent failures on that account.

The deer problem is another situation. Generally, because the woodlands with which we deal are interspersed with agricultural lands, deer while impacting the growth of regeneration, do not completely eliminate it. However, we do have several situations, where deer have simply eliminated any seedlings or stump sprouts leaving us with a very parklike stand with no understory. We still have seed producing trees present but have not been able to produce sufficient seed to supply the needs of wildlife and still allow adequate seedlings to develop beyond the reach of deer.

Hopefully, hunting pressures which eliminate the deer and development of browse in other areas within the deer feeding range will allow reproduction to finally develop. We have not at this point been able to justify the cost of fencing.

Education

Landowners. At this point, I think it is time to talk about the role of the forester as an educator. If a forester is to succeed in his efforts to manage forests, he must be able to convince the owner of the wisdom of the course of action which he is suggesting or he must present the owner with a series of options and the consequences of each. Sometimes a forester must be prepared to change long established ideas. In the case of the initial shelterwood cut, we are flying in the face of the commonly accepted notion that we need to cut the mature (big) trees and release the young (little) trees. It takes work to counter such entrenched ideas. In the case of the stands infested with, or about to be infested with gypsy moth, the owner must be convinced of the need for and the desirability of spraying the stand at critical points in the gypsy moth cycle.

Logging. It is just as critical that the forester educate the logger. A forester has to approach the logger as a partner rather than an adversary. As is the case of the owner, there is a need to change well-entrenched ideas. The first time we had a sale which was "marked to leave" the most common comment was "I'd rather cut the trees with paint." Two things here, the loggers were used to cutting the trees with paint on them and these were generally the most valuable trees in the stand. It has been a slow process, but over the years more and more loggers are bidding on shelterwood sales. Some loggers, when approached by private landowners about selling timber, are even suggesting that landowners have their stand marked as a shelterwood. Most loggers take pride in their work and want to leave an aesthetically pleasing and properly managed forest. I guess the most

telling comment I have had was from a logger who said, "well, if it were my land that's the way I'd do it."

Just remember working together with the landowner and the logger, a forester can accomplish a lot of forest management. Alienate either and forest management goes out the window.

Conclusions

This has been a hurried summary of the procedures our Company uses to develop oak regeneration through the use of the shelterwood system. I would ike to say over the past 10 years we have had both successes and failures in our regeneration attempts. However, looking back on these efforts and analyzing them led me to the conclusion that regenerating oak through the use of the shelterwood system is possible provided we are willing to consider the biological aspects of place and time while conducting our operations and provided we have the patience to accept nature's time table for seed production.

INSECTS AND OTHER PESTS AFFECTING OAK REGENERATION

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ABSTRACT

Research on insects affecting oak regeneration and efforts to establish oak seedlings by acorn plantings in the forest understory have revealed a host of insect and other animal problems. In Ohio, significant establishment of white oak seedlings has occurred in only one area in the past 4 years. Establishment of red oak seedlings was not significant in 1987 even though the 1986 crop was heavy to bumper in most areas. In this paper we discuss the interplay of acorn crop size, insects, litter depth, and animal predation, and how these factors affect oak seedling establishment.

Introduction

Foresters need little introduction to the problem of oak regeneration, that is, the failure of oak to occur in desired numbers and sizes in regenerating stands that prior to harvest were mainly oak. Our research project at Delaware, Ohio, was established in 1983 to determine the effect, if any, of insects on oak regeneration. In this paper we give an overview of our findings to date and offer suggestions on achieving oak regeneration.

Damage to Germinating Acorns and New Seedlings

Most foresters are aware of the damage to acorns caused by Curculio weevils, acorn moths, and gall wasps. Annually, about 50 percent of the acorn crop is destroyed by these "worms." However, few foresters are aware of the impact of insect damage to germinating acorns. We have been studying insect damage to acorns once they begin germination. Before 1983, research in this area had been limited.

In Ohio, the most important pests of germinating acorns and new seedlings, in order of importance, are:

1. An acorn weevil--Conotrachelus posticatus Boheman
2. A sap beetle (nitidulid)--Stelidota octomaculata (Say)
3. An acorn weevil--Conotrachelus naso LeConte
4. An acorn moth--Valentinia glandulella (Riley)
5. A seedling weevil--Barypeithes pellucidus (Boheman)

The weevil C. posticatus affects both white and red oak acorns in the fall and spring. C. naso affects white oak acorns in the fall, rarely breeding in damaged red oak acorns. The biologies and some of the life histories of these weevils were reported by Gibson (1964), who did not indicate the serious damage to germinating acorns caused by these insects. For example, a single C. posticatus weevil can, in one night, destroy or damage the radicles or shoots of several acorns. And preliminary studies indicate that C. naso can damage several acorns in one day. Once the radicle is heavily damaged, successful rooting is rare because the radicle dies or breaks off as it penetrates the soil. Acorn radicles damaged by these weevils appear to have died from desiccation. No doubt, many foresters would assume that the radicle died from lack of water. These weevils also breed in the acorns; this can result in the complete destruction of heavily infested acorns.

The nitidulid or sap beetle, S. octomaculata, is a newly reported pest of acorns (Galford 1987a). The biology and breeding habits of this insect are being studied. In Ohio it is one of the most serious pests of germinating red oak acorns in the spring. The overwintering adults become active when red oak acorns begin to germinate and they feed heavily on the radicles. Breeding occurs in the acorn cotyledons and complete destruction of the acorn can occur. This insect is rarely found outside the forest, and is the most abundant of the acorn pests in southern Ohio in the spring. It is a seed breeder and has been reared in the laboratory on maple, hickory, walnut, pecan, and other tree seeds.

The moth V. glandulella can be a primary pest of germinating acorns in both spring and fall (Galford 1986a). In the fall it is mainly a secondary pest, reproducing in acorns damaged by other insects or rodents. However, in the spring it is one of the first of the acorn pests to become active, and damage by the larvae of this insect occurs as soon as acorn germination begins. The tips of the emerging acorn radicles may be eaten first or the larvae may gain entrance to the acorn through splits in the nut shell, where they immediately begin feeding in the cotyledons. Complete acorn destruction by V. glandulella is rare and most infested acorns can produce a seedling. However, acorns infested by V. glandulella are highly attractive to Conotrachelus weevils and S. octomaculata. Follow-up infestation by these insects can complete the destruction of the acorns. In laboratory tests, S. octomaculata significantly preferred V. glandulella-infested acorns over

uninfested acorns for reproduction. This reproductive activity by the sap beetle destroyed acorn viability.

The weevil B. pellucidus was introduced in the United States more than 100 years ago. Nothing was known of its feeding habits until recently when B. pellucidus was found to be a pest of young oak seedlings (Galford 1986b). Adults emerge from the soil in late April to early May and feed on emerging oak seedlings and other plants (Galford 1987b). In years when few oak seedlings are established, this weevil can be damaging, often killing aboveground parts of new seedlings by girdling the stems. In the spring of 1987, more than 20 percent of several thousand new white oak seedlings in one study area were anemic resprouts, the original tops having been killed back at least once by B. pellucidus. The larval habits of this weevil are unknown. Pupae are abundant in the soil under oak trees in early spring. The larvae have been partially reared on oak roots but it is uncertain whether they naturally feed on oak roots. This weevil is abundant in the glaciated areas of central Ohio; it has not been found in the upland, unglaciated areas of southern Ohio.

A survey in the fall of 1986 and spring of 1987 in Ohio provided information on the extreme damage to germinating acorns by insects. In the fall of 1986, insects destroyed nearly 100 percent of the germinating white oak acorns in light-crop areas and about 40 percent in a bumper-crop area. A notable finding was that the depth of the leaf litter had a direct bearing on the success of seedling establishment and insect damage. Establishment was good only in one area in central Ohio, a site where a bumper crop of acorns fell on nearly bare soil. At this site, 98 percent of the rooted acorns had at least some insect damage, though thousands of new seedlings are now present. Apparently, once the acorn radicle penetrates the soil, it can sustain some degree of insect damage without ill effects. In areas with heavy leaf litter, where insect damage to the radicle tip occurs most often, seedling establishment probably will occur only if low insect populations coincide with heavy acorn crops.

Effect of Insects on Seedling Survival and Growth

The impact of insect damage on the survival and growth of understory oak seedlings is unknown. Occasionally there are insect outbreaks that cause visible mortality, but damage usually is moderate and cumulative. Many seedlings simply fail to leaf out in the spring following 2 or 3 years of insect damage in combination with site stresses. We are attempting to determine the impact of insect damage on oak seedlings over a period of years.

From the fall of 1985 to the spring of 1987, we planted 4,800 red oak and 4,800 white oak acorns in the understory of mature oak stands in southern Ohio. One hundred and twenty acorns (each contained in a small 1/2-inch mesh hardware cloth cage) were planted in each of eighty, 1/160-acre plots. Half of the plots are being sprayed with insecticide bi-weekly throughout the growing season for comparison of seedling survival and growth against

unsprayed plots. It is too early to draw conclusions concerning differences in insect damage in sprayed and unsprayed plots. In 1986, control of some pests with Sevin XLR was poor. In 1987, Diazinon was used. However, the seedlings were heavily damaged by the Asiatic oak weevil, Crytepistomus castaneus (Roelofs), in 1987, so additional changes in insecticides may be warranted.

This study also shows that factors other than insects limit the establishment of oaks in the forest understory. Although the acorns in our studies were "protected" in 1/2-inch mesh hardware cloth cages, about half of them were lost to rodents. One-quarter-inch hardware cloth reduced rodent damage, but heavily damaged the roots of seedlings. We are testing new methods for protecting acorns from rodent damage. Studies to date indicate that fall-planted acorns are as likely to be destroyed by rodents as those planted in the spring, and that some form of protection is a must.

In addition to our studies with screen cages, we evaluated the rodent-repellent RO-PEL. Although RO-PEL supposedly contains the bitterest substance known to man, it did not deter rodents. Another technique evaluated without success was spraying plots thoroughly with aerosol Tree Tanglefoot. In some cases, rodents dug up all of the acorns within 48 hours after this material was applied.

Besides digging up the acorns, rodents also feed on new seedlings. In some areas, more than 80 percent of the surviving seedlings have been chewed off one or more times. We believe that chipmunks and other small mammals are responsible for this damage, though their feeding activity has not been observed.

Prescribed Burning

Our project recently completed preliminary studies on the effects of prescribed burning on insect populations. Two prescribed burns were conducted on the Athens Ranger District of the Wayne-Hoosier National Forest in Hocking County, Ohio, in the spring of 1984 and 1985. Surveys of pest insect numbers in the burned and adjacent unburned areas indicate that populations of C. posticatus and S. octomaculata were reduced following a moderate-to-severe burn (Wright 1986, 1987). Further, numbers of C. posticatus were low for several months following the burn, probably because the burned-over area had insufficient leaf litter for their survival.

These results indicate that under proper conditions, and at the appropriate time in an insect's life cycle, prescribed burning could reduce populations of certain insect pests of oak regeneration. A moderate-intensity burn might kill the insects present in the litter and reduce the litter on the forest floor, making the area uninhabitable for some time.

We are especially interested in evaluating the effects of a fall burn synchronized with a good acorn crop. Fall is the peak feeding and reproductive period of most of the acorn insects, so a burn conducted just

before acorn drop probably would be effective in reducing insect populations and preparing a better seedbed for the acorns. Opportunities for such a burn will be limited. But if success could be demonstrated, some of the problems associated with spring burns would be eliminated. These problems include the possible adverse effects of burning on nesting wildlife and no effect on oak regeneration should a poor acorn crop occur in the year of the burn.

Oak Insect-Tree Disease Interactions

Soil-inhabiting fungi such as Fusarium, Cylindrocladium, Rhizoctonia, Pythium, and Phytophthora cause damping-off diseases in oak. Losses may be heavy (25 to 50 percent) in pre- and post-emergence seedlings. The fungi attack the developing radicles, killing the seedlings 30 to 35 days after they emerge. It is not known whether insects are involved in predisposing germinating acorns to damping-off fungi in the forest. But injury resulting from the feeding/breeding activities of acorn-damaging insects could provide courts of entry for pathogenic organisms that affect germinating acorns and oak seedlings.

We have evaluated the interactions of oak insects and pathogenic fungi in laboratory and greenhouse studies. C. posticatus was used in these studies. Two fungi have been evaluated: Cylindrocladium scoparium and Fusarium solani. We have demonstrated that there is greater mortality among fungus-inoculated acorns that subsequently are subjected to weevil feeding than among acorns subjected to weevil feeding or fungus infection separately. In some tests, 80 to 90 percent of the germinating acorns were killed by a combination of the disease and insect feeding. C. scoparium caused greater mortality than F. solani.

These experiments have demonstrated the significance of insect feeding in predisposing germinating acorns to pathogenic fungi. Research is needed to determine if these same insect/fungus interactions are responsible for mortality in germinating acorns and seedlings under forest conditions.

Discussion

Although we have learned much about the biology and behavior of some of the insects involved in oak regeneration, there is yet much to learn, especially about the impact of these pests over time. And there are other insect pests that have not yet been studied. For example, we have not studied insect damage to oak stump sprouts in regenerating stands, nor have root-feeding insects been studied in detail. We can say at this time that insects are a limiting factor in the establishment of oak seedlings in most years. In years when acorn insect populations are high, seedling establishment will not be significant even in the absence of any animal predation. Good establishment and survival will require reduced populations of rodents and insects coincident with a good acorn crop and favorable climatic conditions.

On the basis of the evidence to date and the results of current research, we suggest that:

1. Heavy leaf litter promotes insect damage to germinating acorns and is detrimental to seedling establishment and survival. Prescribed burning if timed properly should reduce leaf litter and insect populations and, therefore, benefit oak regeneration.

2. Site preparation by disking in years of heavy acorn crops might be beneficial on some sites, especially for northern red oak. Acorns covered with soil are less prone to insect damage and rodent predation. Since 1983, establishment of red oak seedlings has occurred in our study areas only from rodent-buried (probably squirrel) acorns.

3. If you direct-seed acorns, be sure to use quality seed. In 1987 we planted 2,400 red oak acorns from one tree. More than 70 percent of the resulting seedlings died of a possible genetic disorder traced to the seed source. The seedlings ranged from pure albino to normal; most turned brown before they died. Consider planting some of the acorns in a greenhouse-type environment to see if they develop into normal seedlings.

4. There appears to be no safe time to plant acorns. Rodents can be as damaging in fall as in spring. Although there are indications that the best growing sites had more rodent and insect activity, medium sites also were damaged. The heaviest rodent activity begins in early May. Significant insect and rodent damage has occurred to acorns planted in June and July, so late planting is not a solution.

5. There are problems connected with oak regeneration even where seedlings reach the sapling and small pole stage. At this stage the trees are prone to attack from borers that can suppress growth, ruin form and quality, or even kill the trees. Young oak stands growing near mature stands are the most susceptible to borer attack. Borers breeding in the limbs of large nearby trees can migrate to the young stand and cause significant damage. In Ohio, the living beech borer, Goes pulverulentus (Hald.) is damaging in young stands of red oak 2 to 6 inches in d.b.h. Oak stands managed in a block pattern of alternating mature stands and young stands will suffer heavy borer damage, especially if the management units are small (fewer than 20 acres).

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HARDWOODS AND SITE QUALITY

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ABSTRACT

Species composition of hardwood stands in the Appalachians is closely related to site quality, which itself is correlated with available soil moisture during the growing season. Mesophytic species, such as yellow-poplar and sugar maple, dominate moist, high-quality sites, while drought-tolerant species such as the oaks dominate drier, lower quality sites. Some species, such as red maple and sassafras, occur on all sites. Site quality is commonly expressed by site index, but many potential sources of error may seriously bias estimates. Soil-site relationships are discussed as an alternative method of site quality evaluation.

Introduction

The varied climate, tcpography, and soils of the Appalachians create a wide range of habitats for an estimated 150 indigenous tree species. Foresters have a variety of options available for stand regeneration depending on the site requirements, shade tolerance, and other silvical characteristics of the desired management species. Perhaps the first question that the forester planning harvest and regeneration needs to ask is: "Which species should I attempt to regenerate on this site?" Sometimes, however, the manager does not ask a followup question: "Which species are likely to occupy the site naturally?" If the two answers do not agree, the manager will face an uphill battle against nature that cannot be won economically. Much of the time, the correct answers depend on site quality, because in the Appalachians there is a strong relationship between site and species composition. The first purpose of my paper is to review the general relationships between species composition and site quality in the Appalachian region, which includes the Appalachian, Allegheny, and Cumberland Mountains, their associated plateaus, and the Ridge and Valley Province. The second part of my paper concerns estimation of site quality using site index and soil-site relationships.

The Effect of Site Quality on Species Composition

About 90 percent of the tree species in the region are hardwoods. In the mountains hardwood species occur in various mixtures, forming many forest cover types. For example, over 16 principal cover types are recognized in the Appalachians (Society of American Foresters 1980). Some cover types are easily identifiable because few species are present and types change abruptly with slight changes in site. Others consist of many species, have overlapping boundaries, and appear to be less site dependent. Many cover types, however, have one thing in common that we can use to understand the interrelationship between species composition and site quality: most species in a stand respond similarly to the site's soil moisture regime. Although other silvical characteristics are also important, such as shade tolerance, I will mainly use the moisture relationship to group species according to the site conditions necessary for their establishment and growth.

In 1926, the Society of American Foresters developed a very general classification of Appalachian forest vegetation based largely on site and species moisture relationships. Three types of hardwood forests were recognized: (1) moist slope and cove forest, (2) dry slope and ridge forest, and (3) northern forest. The northern forest is found above 4,500 feet elevation in the southern Appalachians and at lower elevations in the central Appalachians. Because the northern forest consists of mesophytic species, some of which are also found at lower elevations, I combine it with the moist slope forest. Awareness and recognition of these forest types is important because, with several exceptions, species composition of regeneration generally will closely resemble that of the overstory. For each type of forest, I briefly describe the general species composition of the mature overstory. Other authors in this workshop describe expected species of regeneration in greater detail.

Moist Slope and Cove Forest

About a third of the commercial forest area consists of moist slopes and coves, which may be characterized as having a cool environment with generally adequate to marginal soil moisture during the growing season. Cove forests occur at elevations between 2,000 to 4,500 feet elevations in the southern Appalachians, and extend up to about 3,500 feet in the central Appalachians. The cove forest is a mixture of many species, and throughout the region typically consists mostly of yellow-poplar, northern red oak, and white oak. Other mesophytic canopy species present in smaller numbers, or not at all, are: white ash, black locust, basswood, walnuts, buckeye, black cherry, red maple, sweet birch, blackgum, cucumbertree, and hickories. Understory tree and shrub associates commonly include flowering dogwood, Fraser magnolia, eastern hophornbeam, sassafras, American hornbeam, striped and mountain maples, serviceberries, redbud, rhododendrons and witch-hazel. Carolina silverbell is a midstory constituent of some stands in the southern mountains. Eastern hemlock and eastern white pine are sometimes also present. Ground vegetation in coves usually consists of a dense herbaceous

layer of ferns and spring ephemerals including squirrel corn, springbeauty, mayapple, and other moist-site species.

The composition of the cove forest varies with geographical area and from stand to stand, with species and abundance depending on local topographic conditions, soils, elevation, and past stand management. The moist slope forest occurs on northerly aspects and has a species composition dominated by yellow-poplar, other cove hardwoods, and, previously, American chestnut. Below 3,500 feet in the southern region, and lower in the central region, white oak is associated with a large number of other species on benches and lower slopes; in the Piedmont, it is on the better soils. The northern forest occurs on moist, northerly slopes at elevations above 4,500 feet elevation in the southern Appalachians, and has a species composition similar to that found on moist sites at lower elevations in the central mountains. In the central Appalachians, the northern forest may also enter coves. Sugar maple, American beech, and yellow birch make up much of the stand. Other associated species are buckeye, basswood, cucumbertree, white ash, black cherry, and northern red oak. Hemlock, and sometimes red spruce and balsam fir are associated conifers. On the Cumberland and Allegheny Plateaus, sugar maple can predominate at lower elevations. Perhaps the best development of the mixed mesophytic forest is in the Cumberland Mountains, where an exceptionally uniform mixture of moist-site species occurs on all but the driest slopes. The moist slope and cove forest may be described as occupying good to excellent sites. Site index of stands on these sites exceeds 105 for yellow-poplar and is above 75 for northern red oak.

Dry Slope and Ridge Forests

Over half of the forest in the Appalachians is on ridges and dry slopes with southerly and westerly aspects, where soil moisture deficits typically occur during the middle to late part of the growing season. This forest type is characterized by drought-tolerant species, mostly oaks, and often includes small stands of mesic-site species in ravines. Chestnut oak and black oak are widespread dry-site species that can occur in extensive, almost pure stands. Chestnut oak occupies a range from below 1,000 in the central Appalachians to about 4,500 feet in the southern mountains. Black oak is found at elevations to 4,000 feet and is an important hardwood in the foothills. Other associated species include scarlet and white oaks, black locust, black cherry, blackgum, and red maple. Southern red oak is a component on dry plateau sites below 1,000 feet in the north and 2,000 feet in the south. Post and blackjack oaks are found on very dry, poor quality sites, usually below 2,000 feet elevation. Understory trees include flowering dogwood, sourwood, sassafras, and American hornbeam. Bear oak is common on dry upper slopes in the ridge and valley province. Shrub associates include mountain-laurel, flame azalea, trailing arbutus, blueberries and huckleberries. Oatgrass may be present in the herbaceous layer along with New Jersey tea, pussytoes, and other dry-site species. White pine is an associate of chestnut oak in the Appalachians. Shortleaf and pitch pines can become a more important canopy component on dry sites in the intermountain basins and plateaus.

Implications for Management

The commercial values of timber species change along with consumer preferences, but recommendations can be made about the relative values of hardwood species for management. Because certain groups of hardwoods are likely to be associated with specific sites in the Appalachians, it would be a mistake to favor the presently popular "right species" on the wrong site. For example, yellow-poplar is a mesophytic species that grows and develops best in coves and on lower elevation moist slopes. Yellow-poplar also occurs on lower quality sites, but its growth, form, and high value there is less than that of the oaks, which are better adapted to dry sites. Dry-site species can grow well on moist sites, but the reverse is not generally true. Likewise, some species, such as dogwood and striped maple are well adapted to moist sites, but are not desirable from a timber standpoint because of their poor form, small size, and low quality. In 1931, Frothingham developed a list of desirable and undesirable timber species for moist and dry sites in the Appalachians, Table 1. Now, over 50 years later, I think it is still generally applicable for forest management.

In summary, because general species composition is so closely correlated with site quality, classifying sites is one of the first steps necessary in planning for management and regeneration. Both timber yields and product quality will be improved if mesophytic species are favored on moist sites, and oaks are grown on dryer slopes. The forester should recall that in mixed species stands, site quality alone will not indicate exact species composition; more detailed ecological models are needed for that. On moist sites oaks and other species with intermediate shade tolerance will likely not be successfully regenerated without special attention. And evaluation of site quality is not always easy. In general, however, the species occupying a stand before harvest are good indicators of site quality and potential future composition of regeneration on that site.

Estimation of Site Quality

Site quality is the inherent biological capability of an area to be productive, and for most forest land is considered a fixed quantity that depends mainly on environmental variables. Two approaches are commonly used in estimation of site quality: site index and soil-site relationships. In the former approach, the tree serves as a long-term, continuous recorder of previous environmental characteristics of the site. In the soil-site technique, the forester attempts to predict tree performance from existing site characteristics which have biological implications about the moisture and fertility levels of the site. Each technique has advantages and disadvantages of use. Another method, growth intercept, is based on a relationship between site quality and the first 5 years of height growth after trees have reached breast height. This method is occasionally used to predict site quality for stands between 15 to 20 years of age, and mainly for conifers which produce annual whorls of branches.

Table 1. Desirability of Appalachian hardwood trees for timber production on moist and dry sites (from Frothingham 1931).

Desirable timber even-aged species[a]	Less desirable species	
	Timber species	Minor species[b]
	MOIST-SITE SPECIES	
Ash (sp)	Beech	Birch, river
Basswood (sp)	Buckeye	Blue beech
Birch, sweet	Butternut	Cherry, pin
Birch, yellow	Chestnut*	Chinquapin*
Cherry, black	Coffeetree	Crab apple
Gum, red	Elm (sp)	Dogwood*
Hickory, mockernut	Gum, black*	Hawthorns
Hickory, pignut*	Hickory, bitternut	Holly
Hickory, shagbark	Honeylocust	Hophornbeam
Locust, black*	Maple, red*	Maple, striped
Magnolia, cucumber	Maple, silver	Mulberry, red
Maple, sugar	Oak, pin	Persimmon*
Oak, chinquapin	Oak, shingle	Sassafras*
Oak, northern red	Oak, water	Serviceberry*
Oak, white	Sycamore	Silverbell
Walnut, black		Sourwood*
Yellow-poplar		Willow, black
	DRY-SITE SPECIES	
Hickory, pignut*	Chestnut*	Chinquapin*
Locust, black*	Gum, black*	Dogwood*
Oak, black	Maple, red*	Oak, blackjack
Oak, chestnut	Oak, post	Persimmon*
Oak, southern red	Oak, scarlet	Sassafras*
		Serviceberry*
		Sourwood*

[a] Most of the species that are desirable on moist sites are less desirable where they occur on dry sites.

[b] Generally small tree.

* Species common on both moist and dry sites.

Site Index

Site index (base 50 years) is the most common measure of forest site quality in Appalachian forests. For example, at the first workshop (Smith and Eye 1986), on immature stand management, the papers that referred to site quality used site index classes to quantify it. Foresters sometimes question whether site index is the best measure of site quality and whether a different measure of potential production, such as total cubic volume or mean annual basal area increment, might be more appropriate. At least for the near future, site index is likely to remain in widespread use in the Appalachians.

Because estimates of site index depend largely on the choice of sample trees, foresters should remember the following criteria when using it to estimate site quality:

1. Applicable only to even-aged stands.
2. Sample trees should not have been previously suppressed.
3. Species should be well suited to the site.
4. No evidence of insect-, disease-, fire-, or weather-caused damage.

Even if the above criteria are satisfied, other sources of error are inherent in many site index curves. These errors include sampling bias during curve construction and imprecise curve fitting. In comparison with guide curves, polymorphic curves are generally considered to predict rates of height growth more accurately over a range of sites.

Improper use of site index curves is probably the most common source of error when estimating site quality. Site curves should be applied in the same manner in which the curves were constructed. As a minimum, the user should sample as many trees per site as the researcher used in developing the curves. The effect of sample size on accuracy of predictions is illustrated by Lamson (1980), who developed site index prediction tables for West Virginia oaks and presented estimates of accuracy that can be expected with their application. As shown in Table 2, at least five trees should be sampled in a 50-year-old stand of red oaks to achieve a half-width confidence interval of 3.3 feet. A greater number of trees should be sampled in younger or older stands to achieve a comparable confidence interval.

Table 2. Half-width of the 95-percent confidence interval of the predicted site index when the number of sample trees ranges from 5 to 25 trees (From Lamson 1980).

Stand age	Half-width of confidence interval (± feet) when number of sample trees is				
	5	10	15	20	25
	NORTHERN RED, SCARLET, AND BLACK OAKS				
20	6.2	4.8	4.2	3.8	3.6
50	3.3	3.1	2.9	2.7	2.6
70	5.1	4.0	3.5	3.3	3.1
	WHITE AND CHESTNUT OAKS				
20	7.6	5.9	5.1	4.7	4.4
50	3.4	3.2	3.0	2.8	2.7
70	4.8	3.7	3.2	3.0	2.8

Estimation of site quality in very young stands can also present problems. Many site index curves were developed using data from mature stands where most sample trees were clustered around the basis age of 50 years. Extrapolation of these curves to younger stands, especially stands of sprout origin, can result in overestimates of site index because the period of rapid juvenile height growth is ignored (Zahner et al. 1982).

Assuming that sources of error in sample-tree selection have been controlled or accounted for, two final sources remain: determination of tree age and height. I do not have an easy solution to the problems of accurately determining tree age, which includes counting indistinct annual rings in diffuse porous species, and in trees with heartrot, or trees with false and extra rings. One solution is to use a height-diameter relationship, instead of height and age, to estimate site class (Lamson 1987).

Many errors in site index determination result from errors in tree height measurement. A technique is available that reduces time and increases accuracy when measuring tree height in stands with steep slopes and dense understory shrubs. Long and Mohai (1986) describe a simple method of measurement based on a variable slope distance (not horizontal distance) of the observer from the sample tree. This method allows the user to proceed up the slope from the sample tree to any convenient place where the top is clearly visible. The observer can not only get closer to the tree top, but also can choose an easy travel route without having to maintain a specific horizontal base distance from the tree. Also, the base of the tree does not have to be visible, but the observer must see a point equal to his or her own height. An inexpensive calculator with square root and reciprocal functions is useful to solve the formula for height. The tangent method of measuring tree height (Larsen et al. 1987) is also useful in mountainous terrain and has the advantage of not requiring a distance measurement from the tree or correction for slope. However, a reference pole of known length must be placed against the tree and two equations with trigonometric functions must be solved to determine tree height.

A species desired for management, such as northern red oak, may not be present for site index determination in some stands. Doolittle (1958) prepared site index comparison tables for 10 species in the Southern Appalachians.

Soil-Site Relationships

Site quality may also be evaluated by observing topography and soil characteristics of the stand. Advantages to this approach are:

1. Sample trees are not required.
2. Present rather than past site factors are evaluated.
3. Prediction models can be used in geographical information systems.

Disadvantages are:

1. Published results usually are not available in tabular form, for ease in field application.
2. Relationships may not be available for a desired species or geographical area.
3. Subjective estimates of some topographic variables may be required.
4. Laboratory analysis may be needed for some soil variables.

Perhaps the most serious limitation of soil-site relationships is that the results may be applicable only to a limited geographic regions. Large errors may result if soil-site equations are applied beyond the area where the study was made.

Soil-site studies have been carried out in many parts of the Appalachian region, Table 3. Most have dealt with yellow-poplar and oaks, and have attempted to predict total tree height at 50 years using similar field measurements. Findings from many studies, however, are applicable only to small geographic areas. Especially noteworthy are four field guides developed by Smalley (1979, 1982, 1984, 1986) for classification, evaluation, and mapping of forest sites throughout the Cumberland Mountains and Plateau. The principles developed by Smalley are being tested by industry to identify and evaluate forest productivity in the Allegheny Mountains and Plateau of West Virginia.

Topographic variables, as a group, are the most important determinants of site quality because of their combined influence on the site moisture regime. Aspect is typically the single most important variable because of its effect on the solar radiation received by the site; north facing slopes receive less direct sunlight than south facing slopes. Position on the slope is usually next in importance and serves as a measure of subsurface water received from landforms further upslope. Slope position also accounts for some soil variation, because deep, colluvial soils are on lower positions while shallow residuals are on mid to upper slopes. Lower slope positions are more protected from the drying effect of winds compared to upper slopes. Other topographic variables, such as shape of the slope and gradient, have yielded inconsistent, but locally important, correlations with site quality. Correlations between site quality and elevation also are inconsistent, likely because many studies are conducted over a limited vertical range.

Soil properties measured in soil-site studies are generally related to the volume available for moisture storage and to physical and chemical properties. Thicknesses of the A-horizon, B-horizon, or both are often correlated with site quality, especially for oaks. Soil texture is the most important physical property; fine-textured soils retain moisture better than coarse soils. Occasionally, soil pH is an important chemical property because of its effect on nutrient availability. Some soil properties,

including depth, often must be estimated subjectively. Others may require sample collection and laboratory analysis. Some researchers have found little loss in soil-site correlations by excluding soil variables from prediction equations in the mountains.

Soil mapping designations in the Southern Appalachians generally have not been consistently correlated with site quality, especially for yellow-poplar. Part of the reason seems to be that early soil mapping was based on broad definitions of series which allowed a soil to be placed on many different aspects and slope positions. Another reason is that soil taxonomic criteria may not be important to tree growth. Because weathering of parent rocks is predictable, broad scale geologic maps may be useful in estimation of site quality, at least until more up-to-date maps of mountain soils become available.

Little work has been done on indicator plant species, and some researchers believe they will be of limited value because so much Appalachian forest has been disturbed by past land use. Currently, vegetation is not a very useful indicator of site quality except for very general relationships. For example, ericaceous species are typically associated with dry sites of low quality, while higher quality sites typically have a dense layer of low, herbaceous vegetation which is conspicuous during the early growing season. Information on specific indicator species is not available for most of the Appalachians, but local experience has shown some associations. In the southern Appalachians, for example, blue cohosh and baneberry are typically found on high quality sites. Their absence, however, does not necessarily mean the site is of lower quality.

Where results of soil-site studies are not available, I suggest using topographic and edaphic characteristics as a general indication of the moisture regime and quality of the site. Certain factors are associated with high-quality hardwood sites in the Chattahoochee National Forest (Rightmyer 1987) and should be generally applicable throughout the Appalachians:

Topographic factors

1. Aspect- North and east facing slopes; azimuths from 330 to 120.
2. Position- Lower 1/3 of slopes.
3. Gradient- Gently sloping, 10 to 30 percent.
4. Land surface shape- Concave landforms.

Soil factors

1. Total depth- Over 40 inches.
2. Topsoil (A horizon) thickness- Greater than 6 inches.
3. Texture- Clayey to loamy.

Table 3. Sources of information on forest site classification and hardwood soil-site relationships for various physiographic regions in the Appalachians.

Source	State	Species	Indep. Variables		
			Soil	Topo.	Other
			------Number-----		
	ALLEGHENY MOUNTAINS				
Trimble and Weitzman (1956)	WV,MD	Oaks	1	3	0
Yawney (1964)	WV	Oaks	1	3	0
	ALLEGHENY PLATEAU				
Auchmoody and Smith 1979)	WV	Oaks	1	4	1
Fountain, M.E. (1977)	WV	Oaks	22	3	6
	CUMBERLAND MOUNTAINS				
Smalley (1984)	TN-KY	All	NA	NA	NA
	CUMBERLAND PLATEAU				
Eigel, et al. (1982)	KY	Yel.-Pop.	3	0	2
Honeycutt, et al. (1982)	KY	Wh. Oak	3	2	0
Smalley (1967)	AL	Oaks	0	3	0
Smalley (1979)	AL-GA	All	NA	NA	NA
Smalley (1982)	AL-TN	All	NA	NA	NA
Smalley (1986)	TN-KY	All	NA	NA	NA
	RIDGE AND VALLEY				
Yawney and Trimble (1968)	WV,MD	Oaks	1	2	0
	APPALACHIAN MOUNTAINS				
Doolittle (1957)	NC	Oaks	2	1	0
Ike and Huppuch (1968)	GA	Var.[a/]	2	4	2
McNab (1984)	GA-VA	Yel.-Pop.	0	3	1
	PIEDMONT PLATEAU				
Della-Bianca and Olson (1961)	NC-VA	Oaks, YP	4	2	1

[a/] Oaks; Virginia, pitch, E. white, shortleaf pines; yellow-poplar.

While each of these topographic and soil factors are associated with a good site, combinations of them in the same stand can indicate even higher quality. Effects of these variables, and others not mentioned here, tend to be additive to a point where the biological growth limit of the tree species is reached.

Results of a study of oaks in the Allegheny Plateau, by Auchmoody and Smith (1979) illustrate some important points about soil-site relationships. I extracted a small part of their results, Table 4, to illustrate how oak site index is affected by three of the six variables they found to be important. When slope position, slope gradient, and slope shape are held constant, site quality is high on easterly aspects and increases with increasing precipitation and thickness of the A1 soil horizon. Equivalent site quality can result from various combinations of the same site factors. For example, an estimated site index of 63 can occur in a stand with: (1) south aspect, relatively low precipitation and thick A1 horizon; (2) northeast aspect, moderate precipitation and shallow A1 horizon; or (3) southwest aspect, high rainfall and shallow A1 horizon. Other combinations also can produce sites of equivalent quality.

Table 4. The relationship between site index and selected climatic, soil, and topographic variables for oaks in northwestern West Virginia. Other important site variables are held constant: slope gradient = 50 percent, slope position = upper 25 percent, slope shape = convex. (From Auchmoody and Smith 1979).

Thickness of A1 (in)	Aspect								
	0	45	90	135	180	225	270	315	360
	----------Site Index----------								
	PRECIPITATION = 40 INCHES								
1	55	57	58	56	54	52	51	52	55
2	58	60	61	59	57	54	54	55	58
4	64	66	67	65	63	60	60	61	64
	PRECIPITATION = 42 INCHES								
1	61	63	64	62	60	57	57	58	61
2	64	66	66	65	62	60	60	61	64
4	69	72	72	71	68	66	65	67	69
	PRECIPITATION = 44 INCHES								
1	66	69	69	68	65	63	62	64	66
2	69	72	72	71	68	66	65	67	69
4	75	77	78	77	74	72	71	72	75

I suggest that soil-site relationships be used to confirm estimates of site index classes where few suitable sample trees are present, perhaps due to stand history. If results of site index and soil-site measures are close, then confidence can be placed in the estimate of site quality. However, if the estimates differ by more than 10 to 15 site units, I would reexamine the field data to reduce the possibility of an error that would result in less-than-optimum management during the rotation. First, check the soil-site data by comparing values of the field-measured topographic variables with those obtained from a USGS 7.5 minute quadrangle map. If no obvious errors in the topographic data are found, then revisit the sample points in the stand to determine if less than desirable site trees were selected or if there were errors in measurement and recording of height or site factors. If no apparent source of discrepancy can be found, then I would use the site index estimate as a measure of site quality.

Summary

The soil moisture regime is the single most important site factor to consider when evaluating site quality and regeneration of stands in the Appalachians. While moisture relations of the site cannot be changed, species composition can be altered to match moisture relations. The manager should remember the following:

1. Species composition is closely correlated with site quality.
   a. High quality sites will usually be dominated by yellow-poplar, sugar maple, and other mesophytic species.
   b. Lower quality sites will typically be dominated by oaks and other drought-resistant species.
   c. A few species, such as red maple and sassafras, are adaptable to a variety of sites.
2. Previous stand history often has an important effect on the presence of certain species; such as those with intermediate tolerance on moist sites.
3. Site index estimates in cut-over, high-graded stands should be checked with soil-site relationships.

With attention to site quality and knowledge of the relative moisture requirements of the desirable forest tree species in the area, the forest manager should be able to predict the future composition of the regenerated stand with considerable precision.

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GYPSY MOTH AND REGENERATING APPALACHIAN HARDWOOD STANDS

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ABSTRACT

Gypsy moth defoliation can affect the natural regeneration of Appalachian hardwood stands in several ways. Actual and potential impacts on the regeneration process are outlined briefly. Regeneration treatments that may minimize these impacts are recommended based on ecological and silvicultural background information on the interaction of the insects and their hosts. Silvicultural guidelines are presented that match the proper prescription to existing stand and insect population conditions. Pre-outbreak prescriptions focus on early harvest before defoliation that will preserve established advance regeneration, seed production capacity, and stump sprouting potential. Outbreak prescriptions protect shelterwood-cut stands, while post-outbreak prescriptions salvage dead trees and regenerate mature or understocked stands. Conversion of stands to nonpreferred host trees and creation of more diversity are long-term options for reducing gypsy moth impacts.

Introduction

The influence of the gyspy moth on natural regeneration of the three Appalachian hardwood forest types varies considerably according to the susceptibility of the type to gypsy moth defoliation. The single most important factor determining the susceptibility of a stand is its species composition. Mosher (1915) established that gypsy moth larvae favored certain trees and plants over others, depending on the insect's stage of development (Table 1). This classification of the more common tree and shrub species into these four groups or food preference classes can be used to determine stand-level susceptibility.

Oaks are most highly favored by the gypsy moth. Since first instar gypsy moths must feed on these highly preferred species in order to survive, stands with few or no highly preferred species present presumably will not support populations of young larvae and are resistant to defoliation.

Table 1: Break down of woody plant species by gypsy moth food preference (susceptibility) classes (adapted from Mosher 1915).

Class I: Species that are favored food for gypsy moth larvae during all larval stages.

Overstory: apple; basswood (American linden); bigtooth and quaking aspen; gray, paper (white), and river birch; boxelder; larch (tamarack); American mountain-ash; all oak species; lombardy poplar; sweetgum; willow.

Understory: alder, hawthorn, hazelnut, eastern hophornbeam, serviceberry, all sumac species, witch-hazel

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Class II: Species that are favored food for gypsy moth larvae after the earlier larval stages.

Overstory: chestnut, eastern hemlock, all pine species, all spruce species

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Class III: Nonpreferred species fed upon by later larval stages only when preferred foliage is not available.

Overstory: American beech; black (sweet) and yellow birch; blackgum (tupelo); Ohio and yellow buckeye; butternut; sweet and black cherry; eastern cottonwood; cucumbertree; American and slippery elm; hackberry; all hickory species; Norway, red, silver, and sugar maple; pear; silver poplar; sassafras; black walnut.

Understory: blueberries, pin cherry, chokecherry, American hornbeam, pawpaw, persimmon, redbud, sourwood, sweetfern.

Class IV: Unfavored species that are rarely fed upon.

Overstory: all ash species, baldcypress, northern catalpa, eastern redcedar, balsam and fraser fir, American holly, horsechestnut, Kentucky coffee-tree, black and honey locust, mulberry, sycamore, tuliptree (yellow-poplar).

Understory: all azalea species, dogwood, elderberry, grape, greenbrier, juniper, mountain and striped maple, rhododendron, all rubus species, sheep and mountain laurel, spicebush, sarsaparilla, all viburnum species

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Conversely, stands with large numbers of highly preferred species have the potential to support large gypsy moth populations. For this reason, the mixed-oak forest type, which encompasses 45 percent of the 248-million-acre eastern hardwood forest, is prime habitat for the gypsy moth. This type is rated moderate to very high in susceptibility.

The Allegheny hardwood type is composed primarily of low to moderate preference species and so is relatively resistant to defoliation. These cherry-maple stands are at greatest risk of defoliation when they occur in the oak-northern hardwood transition zone. There, the cherry-maple stands are intermixed with mixed oak stands or have a sizeable percentage of oak (usually northern red oak) and other preferred species present in the stand. The presence of preferred species allows development of young larvae to the stage where they can then feed on black cherry and red and sugar maples. Most Allegheny hardwood stands would be rated low in susceptibility and only rarely would be defoliated by the gypsy moth.

The cove or mixed hardwood type is characterized by a high diversity of species. The susceptibility of any one stand would depend primarily on the percentage of preferred food species present in the stand. A stand that had 50 percent or more preferred food species would have medium to high susceptiblity, while one that had 40 percent would have low susceptibility, and one that had 20 percent would be resistant to most gypsy moth defoliation. Close proximity of a cove hardwood stand to mixed-oak stands may influence its susceptibility because larvae can disperse from one stand to nearby stands. Cove hardwood stands are highly variable in their susceptibility to gypsy moth defoliation.

The remainder of this paper will focus on the impacts of gypsy moth on the natural regeneration process and how silvicultural treatments can be used to minimize those impacts. The treatments described can be applied to stands in all three Appalachian hardwood types, but are most appropriate for the mixed-oak type because of its higher susceptibility.

Impacts

Each of the four phases in the natural regeneration process can be impacted by gypsy moth defoliation either directly or indirectly. Regeneration treatments must take these potential impacts into consideration or regeneration failures may result.

Phase I--Seed Production and Dissemination

The potential for impact in this phase is high because without seed production, new seedlings cannot be recruited. Oaks flower at the same time early leaf expansion occurs, just after budbreak. Since gypsy moth larvae

are active at this time, it is possible for them to feed directly on flowers, resulting in reductions in seed set and production. There is no evidence to support or refute this potential impact. Heavy defoliation of the tree can reduce the carbohydrates available for production of flowers in the next year, resulting in a reduction in flowering and seed production in the following years. Again, there is no direct evidence to support this impact.

The developing seeds are accumulation points for the tree's carbohydrates, but they are weaker accumulation points than the production of new leaves following defoliation, stem growth, or replenishment of root starch reserves. Light defoliation levels have been shown to significantly reduce seed production but not flowering of English oak. These trees had been sprayed frequently to prevent all feeding and to maintain defoliation levels at less than 5 percent as compared to unsprayed controls that were defoliated 8 to 12 percent (Crawley 1985). The reductions were due primarily to premature acorn drop. Records of acorn production of a mature mixed-oak stand for 15 years show the worst seed years occurring in the years of or following heavy gypsy moth defoliation (Liscinsky 1984). Later records show that acorn production recovered 2 years after defoliation ended (Palmer 1986, unpublished) (Figure 1). This premature drop of acorns is the primary impact of defoliation on seed production (Figure 2). While direct effects of defoliation on seed production are short-lived, mortality of oaks following defoliation results in a permanent loss of seed production.

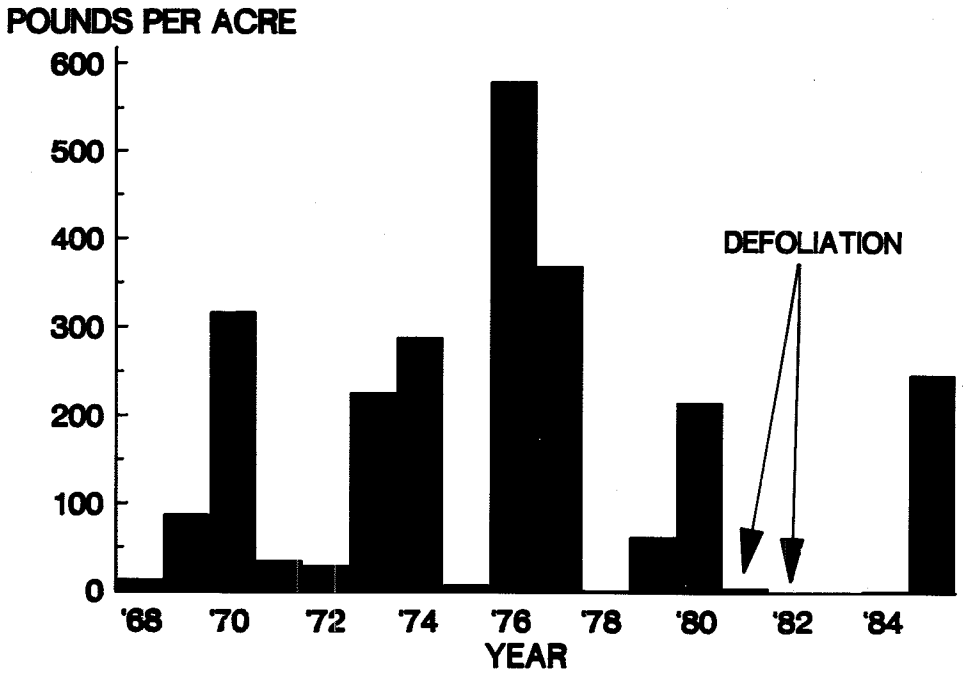

Figure 1. Acorn production of a mixed-oak stand in Huntingdon County, Pennsylvania, from 1968 to 1985. The stand was defoliated by gypsy moth in 1981 and 1982 (Liscinsky 1984 and Palmer).

Figure 2. Aborted acorns produced in year of heavy gypsy moth defoliation. (Photograph courtesy of Dr. Thomas Nichols, VPI & SU).

Phase II--Seedling Establishment

In many areas, seedling establishment is considered nonlimiting in normal regeneration situations. In good to bumper seed years, large quantities of seedlings are produced the following year. While gypsy moth larvae can feed on these young germinating seedlings, there are no serious effects on them as long as the seedlings are attached to the cotyledons. Most seedlings remain attached to their cotyledons for the entire first year; there is relatively little risk. An increase in interfering plants caused by defoliation could reduce germination and early establishment, but again, there is little information to support any interference. Gypsy moth impacts in this phase are minimal.

Phase III---Preharvest Seedling Growth and Development

This is the most critical phase in normal regeneration efforts. Gypsy moths can affect this phase in two ways. The first is defoliation of the seedlings. I do not believe that seedling defoliation will be an important impact. The reason is that these preharvest oak seedlings are normally undergoing a shoot dieback and resprouting cycle that produces large rootstocks that are much older than the shoot. Defoliation may only induce a quicker shoot dieback. The exception would be a new crop of seedlings that have not yet experienced a dieback. Defoliation of these seedlings may reduce seedling numbers more than is normal, particularly in a shelterwood situation.

The second potential impact is interference from other plants that increase in response to the increased light and nutrients present in defoliated stands. Herbaceous plants, such as grasses and ferns, increase in numbers in defoliated stands (Figure 3). These plants compete for light, nutrients, and water with the desirable oak seedlings. In addition, they may have allelopathic effects on the oak seedlings. More shade tolerant tree and shrub species that are present before defoliation also increase in size and numbers following defoliation (Collins 1961; Ehrenfeld 1979; 1980). These less desirable woody plants also compete with the seedlings of more desirable, but less shade tolerant tree species and prevent their continued growth and development.

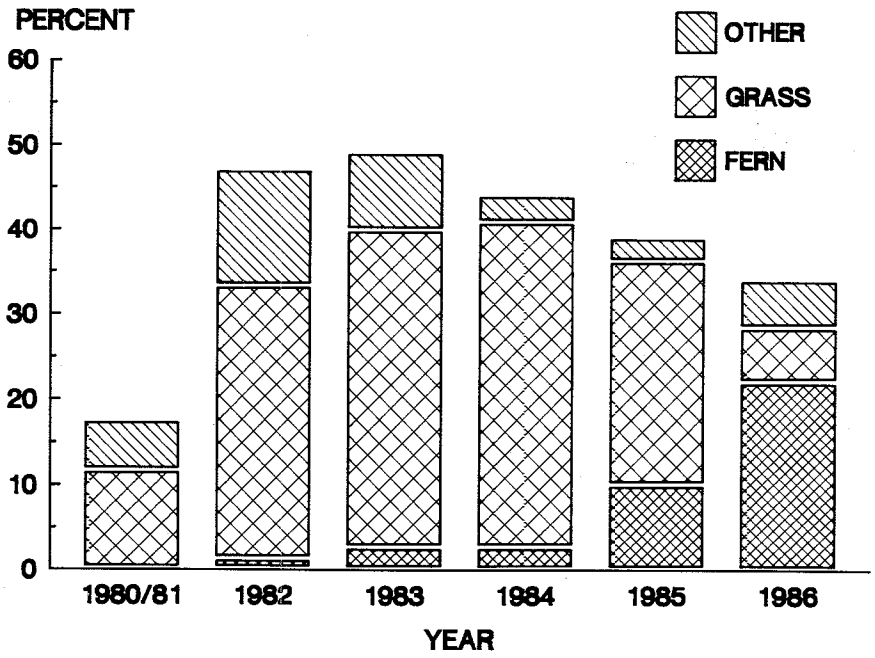

Figure 3. Change in herbaceous ground cover of an uncut mixed-oak stand in Clinton County, Pennsylvania, following defoliation in 1981 and 1982.

The net effect of seedling defoliation reducing preferred oak seedlings and of indirect defoliation effects increasing growth and survival of resistant species, is a change in species composition of new stands. A regeneration survey of stands with heavy mortality in central Pennsylvania showed a dramatic shift to red maple and birch (Figure 4). Along with seed production impacts, impacts on preharvest seedling growth and development are important.

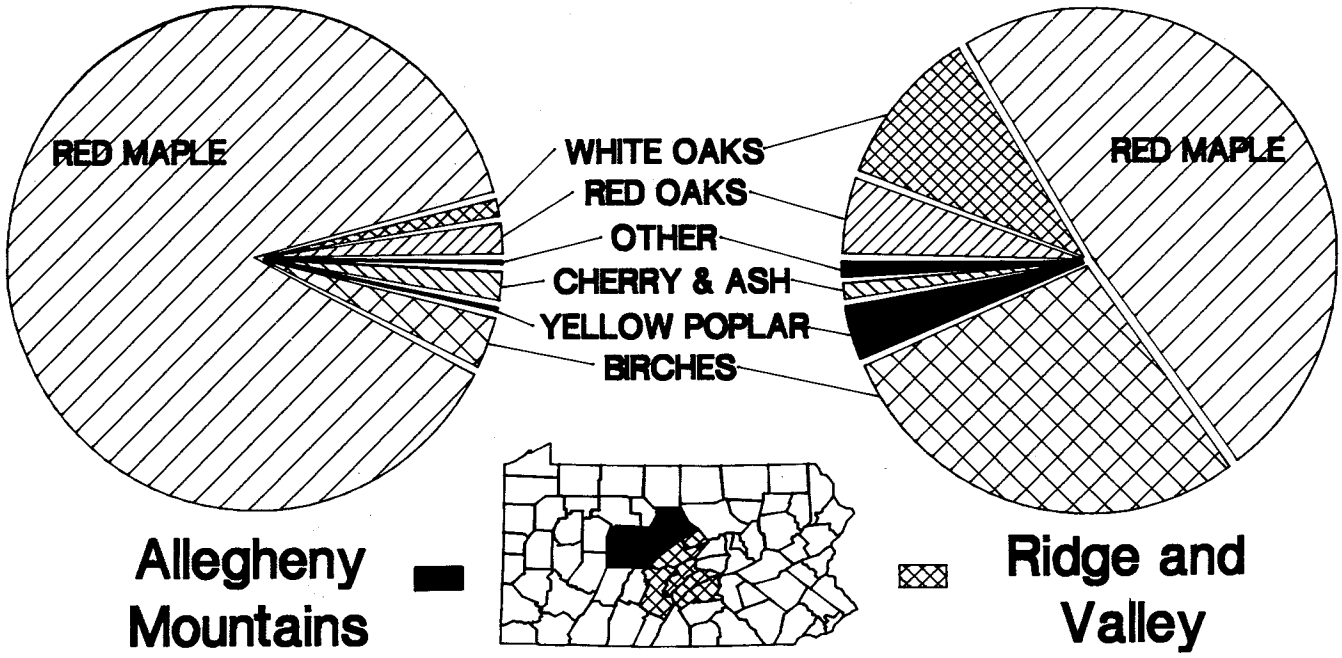

Figure 4. Species composition (1987 percentage of number of stems) of regeneration in mixed-oak stands in the Allegheny Mountains and Ridge and Valley Provinces of central Pennsylvania. Stands were surveyed that suffered heavy mortality following gypsy moth defoliation between 1981 and 1984.

Phase IV--Postharvest Seedling Growth and Development

This phase can also have important impacts. In normal regeneration, large well-established oak seedlings are required before harvest cutting. After harvest, these oak seedlings as well as new seedlings of other species (such as yellow-poplar and aspen) and stump sprouts from the cut trees grow and develop into the new stand. Gypsy moth can affect these new stands in the same ways as with preharvest seedlings: defoliation of seedlings and sprouts and increased interference from other plants. Many young clearcuts (1 to 20 years old) in Pennsylvania have not been defoliated while the older oak stands surrounding them have been totally defoliated (Figure 5). We do not know whether this phenomenon is due to an innate resistance of young stands or to a change in species composition (diversity) of the stands. It is possible that young stands do not have adequate refuges to allow larvae to escape predators and the hotter, drier microclimatic conditions present. Indeed, if young stands are resistant, then we need to know at what age or stage of development they become susceptible again. Stands of 40 to 50 years of age are susceptible, so somewhere between 20 and 40 years of age is a critical point in their development.

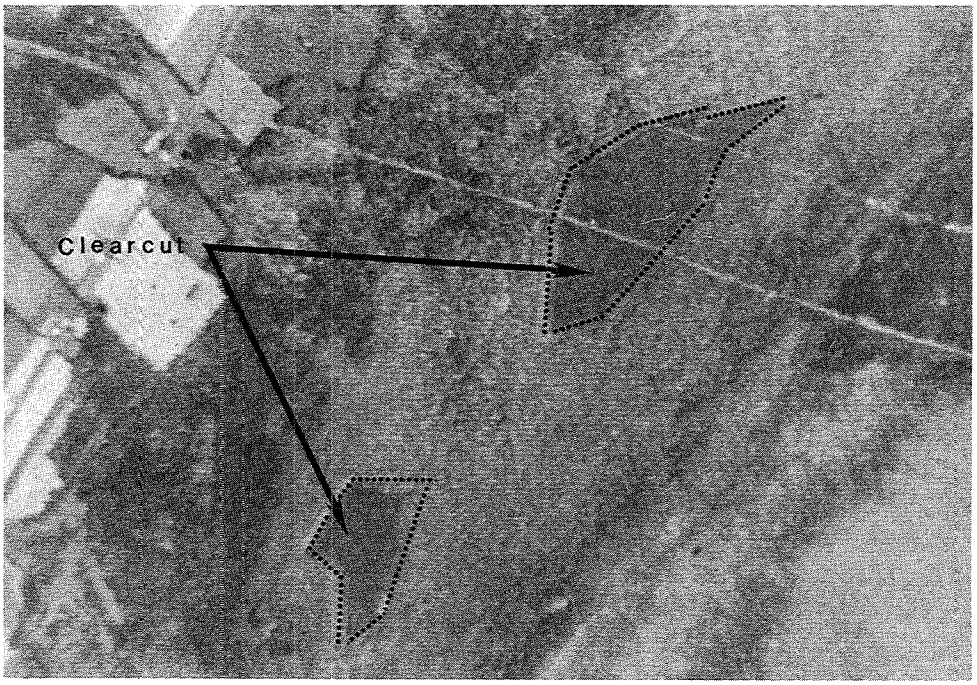

Figure 5. Two young clearcuts in the Ridge and Valley Province of Central Pennsylvania that were not defoliated in 1981, while the surrounding sawtimber-sized stands were heavily defoliated (dark gray depicts healthy foliage in clearcuts (inside of black outlines), while light gray depicts defoliated trees).

We do know that defoliation just prior to harvest cutting will increase the interfering plants and make postharvest regeneration growth and development more difficult.

Another serious effect on postharvest development concerns stump sprouting. Stump sprouts are the only reliable form of oak regeneration in many areas (Gottschalk 1983). Defoliation of trees shortly before harvest cutting can reduce their root-starch reserves. Stump sprouts depend on these reserves for early growth. Lower reserves may result in fewer sprouts and less vigorous growth, allowing invasion of the root system by Armillaria mellea, the shoestring root rot. The fungus then girdles and kills the stump and its sprouts (Figure 6). Heavy defoliation before harvest cutting also kills overstory trees. These dead trees do not sprout after harvesting, so their potential contribution to the new stand is lost permanently.

Summary of Impacts

The cumulative effect of these impacts is that gypsy moth defoliation makes it extremely difficult, if not impossible, to naturally regenerate many mixed-oak stands. These stands may become dominated by herbaceous and less

desirable woody plants for many years, especially on lower quality sites. Expensive ameliorative treatments would be required to re-establish forest stands. Other stands may regenerate successfully after defoliation, but the composition of the new stands is altered to species that are more resistant to gypsy moth defoliation and often less valuable. On many sites, especially high-quality ones, gypsy moth defoliation has accelerated the natural successional process from oaks towards a tolerant mixed hardwood climax forest. In many areas of New England, this successional progression has occurred (Campbell and Sloan 1977, Campbell 1979). These altered long-term ecological trends probably will be the single most important impact of the gypsy moth in eastern hardwood forests.

Figure 6. Black oak stump sprouts that have been girdled and killed by Armillaria mellea in their second growing season. The parent tree was heavily defoliated once, the year before cutting.

Silvicultural Guidelines

Recognizing the impacts that gypsy moth can have on the natural regeneration process is the first step toward reducing those impacts. Guidelines have been developed to modify normal regeneration treatments to minimize gypsy moth impacts. The guidelines are divided into prescriptions that depend on stand and insect conditions, especially the imminence of defoliation.

Defoliation Not Imminent Within 3 To 5 Years or More

When there is adequate lead time before defoliation, stands that qualify for regeneration must have either an unacceptable density (less than C-level) of acceptable growing stock or be within 5 years of maturity. The proper prescription is to regenerate these stands to bring them back into production in the former situation. Or, in the latter, to regenerate these stands before defoliation in order to retain advanced regeneration, seed production, and stump sprouting potential. The young regenerated stands will not be susceptible to gypsy moth defoliation for at least 20 years, reducing the forested area that must be considered for expensive pest controls or losses. The advanced regeneration stocking and site and stand susceptibility and vulnerability should be evaluated to determine which of the following three regeneration prescriptions is appropriate.

Presalvage Harvest. When there is adequate advanced regeneration and/or stump sprouting potential present, the primary objective is to harvest the stand before defoliation. This treatment utilizes the adequate advanced regeneration present, preserves stump sprouting, and prevents loss of value of the mature trees by presalvaging them before defoliation and mortality occur. The new stand may be similar in composition to the previous stand or may differ if the advanced regeneration is different and satisfies management objectives.

Presalvage Shelterwood. Advanced regeneration and/or stump sprouting potential stocking is not adequate, so the primary objective is to develop adequate regeneration by shelterwood cutting. This treatment preserves seed production potential, utilizes stump sprouting from smaller desirable stems, and reduces value loss by presalvaging a portion of the stand. If large numbers of undesirable understory stems or herbaceous cover are present, it may be necessary to control them before the shelterwood seed cut (Gottschalk 1983, Loftis 1985). Selection of trees to be left in the overstory should be based on seed productivity, species desired, crown condition, and spacing. These residual trees may also reduce the stand's susceptibility and vulnerability once the stand has recovered from the initial stress of the cutting. The species composition of the residual stand may be shifted by the shelterwood cut if desired. When advanced regeneration stocking becomes adequate, usually in 5 to 7 years (although oaks may take longer), the residual overstory can be removed. If heavy defoliation becomes imminent before regeneration is obtained, it may be necessary to protect these stands.

Sanitation Conversion. The primary objective is to reduce susceptibility and/or vulnerability by active conversion of these stands away from preferred species before infestation by the gypsy moth. Because of high susceptibility and/or vulnerability, these stands will have either frequent, high defoliation levels or high mortality levels. Lower quality sites could be converted naturally to pines such as white, Virginia, and pitch or artificially to pitch-loblolly hybrids or other conifers. Higher quality sites could be converted naturally to mixed hardwoods, hemlock, or northern hardwoods. Shelterwood cutting may be necessary to obtain adequate advanced regeneration with either natural conversion situation, while artificial conversion may involve substantial costs. Conversion of mixed-oak stands to other species may be economically undesirable because oaks are often the most valuable species that grow on these sites. On the other hand, conversion may be more economically desirable in the long run, due to fewer impacts on the stands due to gypsy moth and lower or no costs for protection of the stands.

Defoliation Imminent Within 3 To 5 Years Or Now Occurring

When lead time before defoliation is not adequate, stands that qualify for regeneration must have either an unacceptable (less than C-level) density of acceptable growing stock or be within 10 years of maturity. These stands should be harvested prior to defoliation or as soon as possible if defoliation is already underway. The landowner is facing a tradeoff between liquidating the stand a few years early in order to retain advanced regeneration and stump sprouting potential needed to regenerate oaks on the site versus allowing defoliation and subsequent mortality to occur resulting in loss of value and regeneration potential. These young stands will not be susceptible for a considerable period as stated previously.

Presalvage Harvest. This prescription is exactly the same as the presalvage harvest in the previous section. However, it includes stands that are within 10 years of maturity rather than only those within 5 years of maturity because defoliation is imminent. Harvesting should occur as soon as possible in order to utilize the adequate advanced regeneration present, preserve stump sprouting, and prevent loss of value of the mature trees by presalvaging them before defoliation and mortality occur.

Presalvage Shelterwood with Spray Priority One. This prescription has the same objectives and requirements as the presalvage shelterwood in the previous section. However, since the cutting stress on these stands has temporarily predisposed them to higher vulnerability, and the investment in preserving seed production and stump sprouting potential in order to obtain adequate regeneration is high, these stands are the highest priority for foliage protection by aerial spraying. If gypsy moth population control thresholds are exceeded, these stands must be protected.

Sanitation Conversion. This prescription is exactly the same as the sanitation conversion in the previous section. Since defoliation is imminent, the conversion should be done before defoliation if possible, or as soon afterwards as possible in order to take advantage of any stump sprouting or other regeneration that may be present or to prevent the mortality of conifers that will be used in natural conversion.

Defoliation Has Occurred, Wait 1 To 3 Years For Mortality To Occur

After defoliation has occurred, stands that qualify for regeneration must have either an unacceptable density of acceptable growing stock (probably due to excessive mortality) or be within 10 years of maturity. The proper prescription is to regenerate these stands to bring them into production, while salvaging mortality and minimizing value loss in the former situation. Or in the latter situation, to salvage mortality and minimize their value loss, while bringing them into full production rather than waiting for stand maturity. The bulk of the mortality due to defoliation will occur in one year sometime between 1 and 3 years later. Maximum value is obtained for dead trees if they are harvested within 1 to 2 years after death. Salvage cuttings should be done as soon after the maximum year of mortality as is possible. The advanced regeneration stocking and site and stand susceptibility and vulnerability should be evaluated to determine which of the following three regeneration prescriptions is appropriate.

Salvage Harvest. The primary objectives are to salvage economic value from dead and dying trees and to bring the stand into production utilizing the adequate advanced regeneration stocking and stump sprouting potentials that are present in these stands. A shift in species composition may occur also.

Salvage Shelterwood. The primary objectives are to salvage economic value from dead and dying trees and to develop adequate advanced regeneration by shelterwood cutting, since advanced regeneration and/or stump sprouting potential stocking is not adequate. It may be necessary to cut some live trees for the shelterwood seed cut in addition to salvaging dead trees. The information on shelterwood cutting in the presalvage shelterwood prescription also applies here.

Salvage Conversion. Converting these stands to nonpreferred species and salvaging economic value from dead and dying trees are the primary objectives for these highly susceptible and/or vulnerable stands. The mortality that has occurred may have contributed already to the conversion process by eliminating stump sprouts and seed production of preferred species. The information on conversion in the sanitation conversion prescription applies here also.

Conclusions

Use of the above silvicultural guidelines will allow the smooth conversion to a more resistant forest stand and a more resistant forest due to greater diversity of species compositions and age classes. The guidelines will also provide for the maintenance of an oak component in stands that would not regenerate to oak because of severe gypsy moth impacts.

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POTENTIAL FOR PLANTING HARDWOODS IN THE APPALACHIANS

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ABSTRACT

Artificial regeneration of hardwoods in the Appalachian Region is a desirable management technique to improve species composition in existing forest stands and to ensure regeneration following harvest cuts. The current knowledge on the artificial regeneration of hardwoods show us that considerable work has been accomplished in this area and some techniques can be recommended. However, there are some problem areas that need additional research and refinement to be operational. In areas where artificial regeneration is desired, the need for information on how to achieve it successfully is great. This paper presents a review of literature, personal opinions, a general how-to guide, and recommendations on future research needs.

Introduction

There is a growing concern among foresters, land managers, and the wood using industry that the hardwood forests of the Appalachians are changing in composition. Following regeneration harvest cuts, there appears to be an increase in the proportion of less desirable species. Some of the silvicultural techniques that could maintain or increase the numbers of valuable species are unacceptable to land owners, some ecologists, and the public. Unacceptable techniques include: clearcutting and prescribed burning. In some cases, small clearcut areas produce the desired results without offending anyone. However, they are not always effective and in some instances, they too are viewed with the same distaste as large clearcuts. Smith (1981) reported that circular clearcuts had to be a minimum of one-half acre to achieve species diversity and stem development.

There is a wealth of information on methodology for producing conifer seedlings and successfully establishing conifer plantations. Much of our conifer expertise can be translated directly to hardwood plantation establishment. However, hardwoods do not always respond in a predictable

manner and tested guidelines need to be established. In her extensive review of Appalachian oak management, Fosbroke (1987) devoted only one page to planting and lists just 12 citations; most of which report poor results or techniques too costly for practical application.

In this paper, I review additional reports on the artificial regeneration of hardwoods, interpret current research that may not be widely known, provide general guides, and speculate on the direction of future research.

Why Plant Seedlings?

If natural regeneration is inadequate, planting forest sites may be a means of obtaining satisfactory stocking or to increase species diversity (Gottschalk 1983; Hannah 1987). Planting may be the only alternative on disturbed areas such as surface mines (Davidson and Graves 1987). Conversion of old fields to hardwood plantations would be another situation requiring some type of artificial regeneration.

What Species to Plant

Godman (1985) implied that all hardwood species can be planted and specifically mentioned white ash, northern red oak, black cherry, basswood, butternut, yellow birch, paper birch, and sugar maple for planting in the northern hardwood type.

Species that have been recommended for planting on surface mined areas in the Northeast include red maple, sugar maple, river birch, white ash, green ash, black walnut, sweetgum, yellow-poplar, hybrid poplars (rooted cuttings or greenwood cuttings), black cherry, white oak, and red oak (Vogel 1981). All of these species have been tested and found satisfactory for reclamation plantings. Thus, they also can also be recommended for forest sites in this region.

My experience has been that hardwood species are not always available in sufficient quantities to meet the demand. In some instances quality of planting stock is poor and/or expensive. An example of short supply is that a representative of Peabody Coal Company recently solicited all members of the American Society of Surface Mining and Reclamation seeking 800,000 northern red oak seedlings for the 1988 planting season. He would have preferred direct seeding, but was unable to purchase the 10 to 12 tons of acorns needed for the job.

Establishment Techniques

Planting

Bare root, containerized, or container grown seedlings can be used in the regeneration program. Each has advantages and disadvantages. Bare-root seedlings are usually the least expensive but require greater care when being handled and planted. Containerized seedlings are those grown in a biodegradable container that is planted with the seedling. This system

results in the least disturbance to the root system. Container-grown seedlings, those removed from the container at time of planting, usually are less costly than containerized seedlings because the containers can be reused. There is some chance of root disturbance when the seedlings are removed, but this can be minimized by maintaining the correct moisture content in the growing medium.

Both container systems have the advantage of extending the planting season, and seedlings for planting can be produced in a relatively short time. Nurseries typically produce hardwood seedlings in one growing season. With either container system, plantable seedlings can be produced in 2 to 4 months and they can be grown in greenhouses during winter months. Therefore, if planting needs are known by October or November, seedlings can be produced for March or April planting. This advantage also has implications for the use of genetically improved seed in regeneration efforts.

Conventional planting techniques such as mattock, hoe-dad, shovel, or auger, can be used with either container system. Also, machine planting can be used with some containerized systems.

Planting Before Harvest Cut

Underplanting prior to harvest has been used successfully in some instances. Red oak, white oak, and white pine were planted successfully under a mixed hardwood sawtimber stand three and four seasons before harvest treatments (Tworkoski et al 1986). The treatments included:

1. No cutting - basal area 109 square feet.
2. Light shelterwood - basal area 48 square feet.
3. Clearcutting - basal area 0 square feet.

Average site index for the study area was 70 for white oak at age 50. Three years after treatment, oak seedling survival exceeded 95 percent in the clearcut areas, and was at least 87 percent in the shaded plots. Both height and diameter growth were significantly better in the clearcut areas.

Yellow-poplar and black cherry have also been underplanted successfully in a poor quality oak stand (Francis and Bevins 1985). The 1-0 seedlings were planted in early spring and all stems 1 inch in diameter and larger in the overstory were injected with 2,4-D 6 weeks after planting. A follow-up treatment was performed in the second growing season. After 7 years, yellow-poplar had 95 percent survival, averaged 24 feet in height, and 2.6 inches in diameter. The black cherry plots averaged 92 percent survival, 18 feet tall, and 1.5 inches diameter. No additional treatments are needed in the yellow-poplar plots as they have assumed dominance and suppressed the competition. Black cherry, however, is in a codominant position with oaks and natural yellow-poplar. Additional cleanings will be necessary for the black cherry to attain merchantable size.

Fall Planting

Although spring is usually considered the time to plant seedlings, a fall planting yellow birch, sugar maple, and white ash in Vermont was successful (Hannah and Turner 1981). The planting was performed in October with a mattock using the dug-hole method. Frost heaving, a problem associated with fall planting, did not occur in these plantings. The planting method and soil type, a well-drained to excessively drained sandy loam, probably alleviated frost heaving. After 3 years, survival rates were 68 percent for yellow birch, 75 percent for white ash, and 90 percent for sugar maple.

Growth and survival were both influenced by deer browsing and to a lesser degree by competition from invading Rubus sp. These factors also would affect spring plantings and, therefore, do not diminish the success of the experiment.

I would not hesitate to fall plant on light textured, well drained soils.

Survival

A comparison of containerized and 1-0 black walnut seedlings showed that bare-root seedlings had significantly better survival--94 vs 87 percent. However, the containerized seedlings had significantly better growth (von Althen and Prince 1986).

I have planted both containerized and container grown conifer seedlings. Despite the differences between hardwoods and conifers, I have noted excellent survival of pitch x loblolly containerized pine seedlings on a harsh mine site in southern West Virginia--99 percent after 3 years. Containerized seedlings were used to ensure survival in this genetics test. No bare root seedlings were planted.

Direct Seeding

Some species can be direct seeded. Sugar maple, white ash, yellow birch, paper birch, basswood, and northern red oak are listed by Godman and Mattson (1985a) as species that can be direct seeded in the northern hardwood forest type. To achieve any degree of success with red oak, Godman and Mattson (1985b) recommended scarifying to destroy the habitat and cover of acorn-consuming wildlife, and then sowing pregerminated acorns to accelerate establishment. However, sowing pregerminated acorns is not advocated by other researchers.

Richards et al. (1982) reported that several oak species have shown the best results from direct seeding minesoils in Kentucky. I hand-seeded scarlet oak acorns on two reclaimed surface mines in Pennsylvania with good germination success. Initial growth was slow and I have not visited the sites recently to be able to report on juvenile growth. Neither the Kentucky nor Pennsylvania areas supported rodent or wildlife populations that would consume the acorns.

Black walnut has been seeded successfully on many surface mined areas (Ashby et al. 1978); most of the successful seedings were installed on open minesoil. However, conditions have changed dramatically since the 1970's and direct seeding is no longer as effective. Legislation now requires sowing herbaceous seed. The herbaceous vegetation introduces a competition factor that many tree species cannot overcome. Also, this cover provides habitat for seed eating small mammals. Recent attempts to direct seed black walnut have been successful only where competing vegetation was controlled.

Improving Seedling Establishment

Seedling Quality

Seedling quality refers not only to freedom from diseases and insects, but also to seedling vigor, size, and root-shoot ratio. Johnson et al (1986) recommended 2-0 oak seedlings with a minimum diameter 1 inch above the root collar of at least three-eights of an inch. This value is within the range that we recommend for surface-mine plantings. With diameters of three-eights of an inch and larger, tops should be pruned to approximately equal the length of the roots. Small or defective seedlings that have not been culled by the nursery should be discarded. Most species will achieve the required size as 1-0 seedlings. However, it appears that northern red oak needs 2 years in some nurseries.

Mycorrhizae

Improving the quality of seedlings through mycorrhizal inoculation of the nursery beds can increase both seedling survival and initial growth. Bryan and Kormanik (1977) reported that sweetgum seedlings grown in nursery beds treated with Glomus mosseae or a naturally occurring (unidentified) endomycorrhizae produced twice as many seedlings as the control beds. The 1-0 seedlings from the treated beds were an average of 8 times taller than the nonmycorrhizal controls. Improved growth was also shown in a similar study with black cherry, boxelder, red maple, sugar maple, sweetgum, sycamore, and walnut (Kormanik et al. 1982). Thus, the presence of mycorrhizae may ensure the production of seedlings of large enough size for planting in one season.

It has also been shown these larger, more vigorous seedlings survive and grow better than nursery run seedlings. Field plantings of sycamore and sweetgum showed significantly better survival and growth of mycorrhizal seedlings compared to nonmycorrhizal (Marx 1977).

Site Selection and Fertilization

Site quality is critical to establishing successful hardwood plantations. Johnson et al. (1986) recommended planting red oak on sites having a black oak site index of 65 or better. Godman (1985) recommended planting on fertile, well-drained soils without a heavy clay layer or bedrock within 2 feet of the surface. Horsley (1985) tested various methods of site

preparation to reforest orchard stands and savannahs in Pennsylvania. None of the herbicide, mechanical, or fertilizer site-preparation techniques improved establishment significantly. In fact, some treatments reduced initial survival. Black cherry was the only species tested that showed a positive growth response to the fertilizer treatments.

Pruning and Mulching

A comparison of survival and growth of 1-0, 2-0, and 3-0 northern red oak seedlings subjected to various treatments of top pruning, mulching, and fertilization showed no significant differences between treatments (Wendel 1980). Wendel concluded that 2-0 seedlings, planted properly with an 8-inch power auger to prepare planting holes, offer the best chance for successful establishment.

Top pruning is sometimes used in hardwood planting to reduce moisture stress on the roots. Johnson, et al. (1986), recommended undercutting and top pruning red oak seedlings before they are lifted from the nursery bed.

Survival of red oak seedlings decreased with the severity of root pruning treatments, but height growth differed little among treatments after 4 years in the field. Successful field establishment of dormant northern red oak seedlings was partly dependent on the number of roots left intact after lifting from the nursery bed (Beckjord and Cech 1980). Kormanik (1986) reported that survival and first year growth of sweetgum seedlings were significantly better for seedlings with six or more first order lateral roots than for seedlings with less than six roots. Lateral root development of seedlings grown in nursery seed beds was strongly correlated with height, stem diameter, top weight, and root weight in northern red oak (Ruehle and Kormanik 1986). Ruehle and Kormanik recommended that below-ground seedling development be included as an element in grading northern red oak seedlings.

Improving Post Planting Survival and Growth

Following initial establishment of the seedlings, it often is necessary to implement cultural treatments to ensure continued survival and to maintain or improve seedling growth.

Bare Soil

Experience with planting oaks on forest sites has shown that initial survival is usually satisfactory to excellent. Subsequent growth, however, often is slow resulting in increased mortality from suppression and competition. But our tests on old surface-mine plantings have shown different results. Vogel (1979) reported that hybrid poplars and red oak were the best hardwoods in 30-year-old plantations in Pennsylvania. The red oaks averaged 5.3 inches in dbh and 37 feet in height. Evaluation of another series of plantings showed that red oak grew well in Illinois, Indiana, Ohio, and Pennsylvania. Exceptional growth of red oak was reported by Ashby et al. (1978) in a 35-year-old plantation in Illinois. Trees averaged 9.9 inches in dbh with one individual over 20 inches in dbh and 80

feet tall. No doubt, these results are due to site conditions of the minesoils. Mixing of the overburden created a physical condition which readily allowed penetration by tree roots, and the shattering of the bedrock probably released a new store of minerals. Finally, there was no competing vegetation on the sites. Recent plantings have not done so well. The extensive grading and establishment of herbaceous cover now required by law result in a poor site for tree planting. Growth of prelaw plantings, however, shows the potential of trees on good sites.

Forest Site

Release treatments to reduce competition do not always improve growth. McGee and Loftis (1986) reported on two studies in which northern red oak and black oak were subjected to various cleaning regimes. Results were inconsistent and even the best responses to the cleaning treatments were not sufficient for the oaks to assume dominance.

Old Field Site

In 1981, von Althen reported 5-year results of a field test on the effects of site preparation and postplanting weed control on the survival and growth of black walnut, basswood, white ash, and silver maple seedlings, and hybrid poplar cuttings. Treatments included plowing and disking, either alone or in combination with applications of herbicide. Postplanting treatments consisted of herbicide application following planting and subsequent applications in April of the 2 years after planting. The hybrid poplars failed in the controls and had poor survival in all treatments. Survival of the other four species was increased on all treatments. Height growth of all species was best on the plots completely plowed, disked, and broadcast-treated with herbicide.

Herbicides

Chemical control of herbaceous competition resulted in significantly greater height growth of direct seeded black walnut on minesoils in Illinois (Philo et al. 1983). The best height growth was achieved in treatments that included a single application of Roundup and Princep mixed together, two applications of Roundup, and two applications of the Roundup and Princep mix. A single application of Roundup was ineffective. The increased growth in the three best treatments should be sufficient to ensure the permanent establishment of the black walnut.

A combination of herbicide and cultivation treatments in planted green ash resulted in significantly better height and diameter growth over cultivation alone, herbicide alone, and mulch plus cultivation treatments (Zutter et al 1987). There was a slight but not significant reduction in survival due to the herbicide. In a study comparing mowing to rototilling and chemical weed control in sugar maple plantations, von Althen (1984) concluded that mowing alone is not effective in reducing herbaceous competition.

Fertilizer

Fertilization is not widely practiced as a forest management procedure. However, it could be a means of stimulating initial growth of planted hardwoods to help them achieve a position of dominance in the emerging canopy of newly established stands. Ponder (1980) showed significant growth increases in planted black walnut seedlings fertilized with 12-12-12 fertilizer at the time of planting. Placement and rate of application had a positive but not significant influence on seedling growth. Best growth occurred when fertilizer was mixed with the soil before planting. The rate of 340 grams of fertilizer per seedling, the highest rate tested, resulted in the best growth.

Seedling Protection

Once seedlings are established there may still be problems with deer browsing and girdling by rabbits and small rodents. Several types of protective devices are available. Marquis (1977) reported on seven types of wire or plastic tubes that can be erected around seedlings to protect them from deer browsing. Three types are recommended:

1. 3-foot-diameter tube constructed of 5-foot-tall cattle wire.

2. 6-inch-diameter plastic tube.

3. 1-foot-diameter tube constructed from 5-foot-tall, 2-inch mesh chicken wire.

Cost per installed protective device, respectively, was: $2.75, $1.30, and $1.15. A minimum of 100 seedlings per acre should be protected, so using the chicken wire tubes would cost at least $115 per acre.

Plastic tubes should be used where girdling by small mammals is a potential problem. The small mesh of these tubes will protect the base of the seedlings as well as the tops. A solid plastic tube, used in Great Britain, has two distinct advantages over the open mesh tubes used by Marquis (1977): they provide a microenvironment for accelerated growth and protect the seedlings if herbicide applications are required (Kelty and Kittredge 1986). These tubes are comparable in price to the plastic mesh tubes.

Establishment Costs

Planting

Reports on planting costs vary considerably. Davidson and Graves (1987) reported a cost of 10 cents per seedling, Hensley (1983) reported 15 cents and 37.4 cents per seedling, while Johnson et al. (1986) reported 17.5 cents per seedling. Site preparation costs ranged from fewer than 10 to 18 cents per seedling. The cost of seedlings also varies according to source (private or state nursery), age, size, and species. In these cost studies,

seedling costs were $40.00, $76.00, and $230.00 per thousand, respectively.

Containerized and container-grown seedlings are competitive with private nurseries for species with fibrous roots. A shortcoming of the container systems is that very large containers must be used with tap rooted seedlings such as the oaks. The larger containers are substantially more costly and require additional growth medium, which adds to the cost. One container grower provides hardwood seedlings in 4, 6, 8, and 20 in^3 containers. Oaks are only grown in the 8 and 20 in^3 sizes and black walnut in the 20 in^3 size. Retail costs of the seedlings depend on container size and in 1988 are $160, $240, $300, and $750 per thousand, respectively. These costs do not reflect the cost of containers; the grower requires a deposit which is refunded when the containers are returned. Planting costs for all but the largest containers will be in the same range as planting bare-root seedlings. I have observed comparable planting production rates for both containerized and bare-root seedlings when establishing test plantings.

Direct Seeding

Direct seeding can be inexpensive so long as the site does not require extensive preparation. If direct seeding is used to supplement stocking, I recommend spot seeding. Miniplanting sites can be hand scalped with relative ease. Installing seed spots in this manner would not exceed 20 cents per spot plus seed cost, which might range from less than a penny for readily available, smaller seeded species to 15 or 20 cents for acorns. If the site can be machine seeded, seeding costs should be about $200 per acre.

Reducing Costs

Hand planting tree seedlings is labor intensive. One means of reducing cost is to plant fewer trees per acre. In conjunction with this, obtain the best possible planting stock. Johnson et al. (1986) showed that 9.1 planted trees of 4/16 in shoot diameter are needed to obtain one successful tree, whereas only 2.4 planted trees of 10/16 caliper are needed per successful tree. Larger trees are more expensive, but the added cost is offset by reducing labor by 75 percent. Using larger seedlings also reduces the number of weedings needed to get the seedlings well established.

Summary

The number of literature citations from the past few years indicate the concerns regarding artificial regeneration of hardwoods. Some of the studies cited are optimistic about successfully regenerating some hardwood species, but many problems were encountered in regenerating oaks successfully. Most indicate that initial survival is satisfactory but subsequent growth is slow. In many instances, attempts to accelerate oak growth have not been successful to the degree where oak seedlings can maintain dominance in the future stand.

Cost data were elusive. Some reports allude to the added cost of performing cultural treatments, but none provide estimates of value return or current

value. Fosbroke (1987) recommended not attempting oak regeneration even on the best sites because of the high cost. What is too expensive? Fosbroke (1987) concluded: "The question of how much money people will be willing to spend to ensure future oak regeneration on the best Appalachian sites remains to be answered."

Conclusions

There is a great deal of information on the artificial regeneration of hardwoods. However, voids in our information bank need to be filled before comprehensive guides can be developed. On the basis of experience and available information, the following is offered as a general guide for regenerating hardwoods artificially. As more information becomes available, these guidelines can be made more specific.

1. Site evaluation--Determine past species composition and productivity. Was the site being utilized by the former forest stand? Take soil samples to measure fertility, physical properties, and moisture relations. If the site was not in forest, compare soil type and other parameters to known forest soil types.

2. Species selection--On the basis of the site evaluation, select species with the highest potential for survival and development. If species other than ones with high potential are mandated for any reason, examine the site data to determine what modifications are needed to make the site as acceptable as possible for the species to be planted.

3. Establishment technique--Select the establishment technique. For most plantings, this will probably be to plant seedlings. If underplanting at wide and irregular spacing, consider container-grown or containerized seedlings.

   If seed-consuming animal populations are low and the new stand is to be established on an old field, and equipment is available for site preparation and seeding, or if an interplanting is needed in a stand with low stocking; then consider direct seeding. General rules that have evolved over the years must be followed to achieve any degree of success. These include:

   a. Match the species to the site; i.e. do not seed any species that would not normally grow on the site from natural seed.

   b. Use the best quality seed available.

   c. Time the seeding operation to coincide as closely as possible with natural seedfall. Or stratify the seed as recommended in "Seeds of Woody Plants in the United States" (USDA 1974) to achieve maximum germination.

d. Protect the seed from rodents, birds, and other seed-consuming wildlife.

e. Be prepared to practice weed control to enhance the development of the new seedlings.

4. Site preparation--The degree of site preparation depends on current site conditions and the species to be planted. If a tolerant species is used and competition is light, minimal preparation is sufficient. In heavy competition, especially if intolerant species are to be planted, more intensive preparation is required. Site preparation can be accomplished chemically (herbicides), mechanically, or by a combination of the two. The objectives of site preparation are to provide light and reduce competition to the seeded or planted seedlings.

5. Seedling grades and handling--Good quality seedlings must be used to achieve the highest possible survival and seedling growth. Care must be exercised in handling the seedlings to prevent drying and to minimize transplant shock.

6. After planting care--Provisions must be made to care for the seedlings after planting. This may include fertilization, weeding and cleaning, and possibly protection from browsing.

As more data are gathered on hardwood establishment and juvenile growth, these guidelines should be expanded and made more specific, possibly by species or species group. The following are areas in which information is lacking:

1. Nursery production techniques need to be improved to provide the best possible quality of hardwood seedling for successful outplanting.

2. Techniques are needed to accelerate juvenile growth of hardwood species, especially the oaks, to enable the seedlings to be competitive with less desirable species.

3. Economic information needs to be developed to show cost effectiveness of various cultural practices and break points where added investments should not be made.

4. More precise site-evaluation techniques need to be developed to ensure that species with the highest potential for a particular site are planted.

5. Silviculturists and land managers need to work in closer harmony with the consumers to provide the products they desire and to compromise or seek alternatives when it is impractical to produce the desired products.

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GUIDELINES FOR REMOVING NONMERCHANTABLE SAPLINGS-POLES WHEN APPLYING EVEN-AGE HARVEST PRACTICES

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ABSTRACT

Residual stems are nonmerchantable or cull trees left after the final harvest of the former stand. These trees can affect the development and species composition of the new stand. Residuals should be removed in areas with more than 10 to 20 square feet of basal area per acre. However, from 30 to 80 good quality stems of sugar maple and/or beech may be left in cherry-maple stands to ensure a component of these tolerant species in the new stand. Advanced oak stems of good form are desirable residuals too. Chainsaw felling of residuals is generally the least expensive and most effective method of treating residuals; however, undesirable species may also be killed with chemical treatment in advance of harvest.

Introduction

The final harvest of a hardwood stand using an even-aged silvicultural system will likely leave some residual stems from the old stand. Residuals of concern are primarily those that were a part of the former stand rather than advance regeneration, which is likely to be present when using a multiple-cut harvest system such as seed tree or shelterwood. We are usually concerned with saplings or poles (1.0 to 10.9 inches dbh) and normally consider only the stems in the 2-inch diameter class and larger. Residuals may be left during harvest because they are either below the merchantability size limit for the harvest or are cull; that is, the stems may be of merchantable size but are too crooked, rotten, etc., to be of value. Trees which become residuals, although often the smaller trees in a stand, may be of the same age class as the old stand or may be slow growing shade-tolerant trees which developed and grew under the old stand.

General Guidelines

The general guideline, when timber production is the primary landowner objective, is to kill or remove all residuals larger than 1.5 inches diameter (2-inch class and above) at or before the time the new stand is established (Sander and Clark 1971; Kellison et al. 1981; Marquis et al.

1984; Roach and Gingrich 1968; Little 1967; Sander 1977; Filip 1973; Beck and Della-Bianca 1981). This general guideline will be further modified below and under the discussion of each timber type.

Among the reasons for removing the residual saplings and poles are that these residuals will retard the growth of the regeneration (Beck and Della-Bianca 1981), provide shading and competition to the regeneration (Nichols et al. 1985), and perhaps, if shading is severe enough, eliminate fast-growing shade-intolerants from the regeneration stand (Sander and Clark 1971). The harvest units may be esthetically poorer in appearance if the residuals are not removed (Sander and Clark 1971; Trimble and Rosier 1972). Removal of the residuals is expected to encourage desirable regeneration and may upgrade the productivity of the new stand (Petruncio and Lea 1984). The residuals themselves may die (Trimble and Smith 1963), may deteriorate in quality (epicormics, etc.), or may become wolf trees (Roach and Gingrich 1968). We found, in a Westvaco study, that about 20 square feet per acre of residuals reduced the growth, but not the number of regeneration stems.

The ability of residuals to respond depends upon the species and condition of the trees and whether they are in fact old residuals or are advanced regeneration from a previous disturbance. Advanced regeneration could be left to form the new stand. Our experience at Westvaco shows that poorly formed understory beech trees do not grow well, averaging 0.04 inches in diameter growth per year over 12 years following release. Better formed and younger red maple residuals averaged 0.09 inches per year over 10 years following release. However, even this better response is less than half of the growth we would expect from vigorous, main canopy stems. Carvell (1967) found that flat crowned and leaning oaks respond slowly to release and do not grow as well as straight, well-formed oaks. In contrast, the better residual understory sugar maple and beech stems will respond to release and can be left to form a component of new stands (Marquis 1981a).

Landowner objectives may affect whether or not residuals should be removed. If timber production is the primary objective, then residuals are removed to promote vigorous regeneration growth, alter species composition towards intolerants, and to remove trees and species which are undesirable for timber. However, if wildlife management is a primary objective, hollow understory beech trees could be left to provide den trees and some mast, even if timber growth is sacrificed. Likewise, flowering dogwood might be left for esthetic purposes. Even retaining beech and sugar maple in the cherry-maple type provides species diversity at the expense of the growth of the shade-intolerants such as cherry and yellow-poplar. There are no doubt other exceptions.

While the general recommendation is to remove any residual stem that is 2 inches or larger in diameter, it may not be economically reasonable nor of much biologic consequence to remove relatively small amounts of residuals. General guidelines are:

1. To leave no more than from 10 square feet of basal area per acre (Marquis et al. 1984; Marquis 1981b) to 20 square feet of basal area per acre (Kellison not dated).

2. To remove residuals when more than 20 square feet of basal area per acre is present. Smaller amounts may be removed, especially for esthetic purposes, in areas which have high visibility.

3. In any area where small amounts of residuals are left, the residuals should be well dispersed rather than in clumps.

4. In the case of clumped residuals, density in the clumps is higher than the average stand density and these residuals should be removed.

The minimum amount of residuals which can be left differs by forest type and the minimum for each type will be further considered in the specific forest type discussions below.

Oak-Type

Oak stands would be expected to carry less basal area than stands in the cove or cherry-maple types. Also, basal area of oak stands varies with site; lower sites, at full stocking, have less basal area than high sites. A low-site oak stand might have 90 square feet per acre (trees 1.0 inch dbh and larger) at age 50. A higher number and proportion of the trees, at a given age, in low sites would be left as residuals (Schnur 1937). Therefore, removal of residuals might be more biologically necessary on the low sites and the treatment threshold level should be on the low side; that is, treat as low as 10 square feet of residuals per acre. If as much as 20 square feet of well dispersed residuals were left in oak stands, we could expect the residuals to have an effect on the regeneration. The management guides for the oak type usually specify that all residuals 2 inches diameter and above be removed (Sander and Clark 1971, Roach and Gingrich 1968, Sander 1977).

Advance regeneration is usually needed to successfully regenerate oaks. If sapling size oak stems are cut with the other residuals, the stumps will usually sprout and produce a vigorous stem which will be part of the new stand (Sander 1977). However, if chemical methods are used in oak stands, only the undesirable species should be treated, since an oak killed by chemicals may not provide a sprout for the new stand.

Cherry-Maple Type

Control of residuals in cherry-maple stands will increase the amount of the fast growing shade-intolerants. However, better stems of the understory residuals of the shade-tolerant species, beech and sugar maple, will respond to release and can become a component of the new stand (Marquis

1981). Without a head start, the intolerant species would not be a part of the main canopy of the new stand.

Marquis et al. (1984) make the following recommendation for the Allegheny hardwoods:

> "In stands that contain large saplings and small poles of the tolerant species, it may be desirable to retain 30 to 80 good quality stems per acre (a maximum of 10 square feet of basal area per acre) to ensure their representation in the main crown canopy of the next stand. Trees retained should be 3 to 10 inches dbh, have moderately good crowns and clean, straight boles free of branches and epicormic branches for at least the first 17 feet. The trees to be retained should be carefully marked before cutting so that they are visible at a distance from any angle. This will help to prevent them from being inadvertently cut or damaged during logging."

> "All trees 2 inches dbh and larger, including culls and nonmerchantable trees, should be removed or killed so that they do not interfere with the developing reproduction. If there are more than 10 square feet of saplings and poles in unmerchantable species (such as dogwood, sassafras, striped maple, and so on), they should be treated by stem injection 3 to 12 months prior to cutting to reduce the incidence of sprouting of the undesirable species. However, selected high-quality tolerant residuals may be retained, as previously described."

Cove Type

The cove type has, by definition, a large component of the very shade-intolerant yellow-poplar. Appalachian cove stands often have tolerant understories of such species as flowering dogwood, red maple, and American hornbeam, in amounts of 300 or more stems per acre ranging from 1 to 4 inches in diameter. In one study, 17 square feet of residual basal area was found to reduce height growth of the yellow-poplar regeneration by 40 percent at stand age 18. It is recommended that all residuals be removed (Beck and Della-Bianca 1981).

Removing Residual Stems

Cutting residuals with chainsaws during or after the final harvest is the common method of removing the residual stems and is often cited as being less expensive than chemical treatments (Trimble and Rosier 1972; Petruncio and Lea 1984). Also, if the area is esthetically sensitive, chemical methods would leave standing dead trees while chainsaw felling would provide a better appearance. Chemical methods might be used in advance of harvest on undesirable species, which would reduce sprouting of the treated stems and would reduce the seed supply of the undesirables if the treatment were applied far enough in advance of harvest (Loftis 1985). Loftis (1985) recommends a preharvest treatment of chemical injection of stems 2 inches and larger which is expected to cost $50 to $70 per acre.

Gabriel and Nissen (1974) studied felling of residual trees, ranging from 1 to 9 inches in diameter, during logging in New York. They found that, on the average, a trained worker could fell 87 trees per hour and developed the following equation to determine cost of cutting residuals when removal is done at the time of logging:

$$\text{Cost/A} = \frac{\text{number of trees/A}}{87} \text{ X hourly rate of pay}$$

Postharvest chainsaw felling of residuals might be expected to cost $20 to $30 per acre in areas where both sawtimber and pulpwood have been harvested.

Research-Needed

We generally have enough knowledge to know that we should remove residuals when regenerating hardwood stands. However, more work would be useful in determining the characteristics of residuals which predict growth and mortality (Trimble and Smith 1963). We also need to know the precise density of residuals, in each type, which constitutes a serious impediment to regeneration (McLintock 1987). We should further develop and test methods for reducing the capability of residuals to affect the regeneration (McLintock 1987).

Recommendations

1. Remove residual stems larger than 2 inches diameter when regenerating Appalachian hardwood stands.

2. Stands of residuals of more than 10 to 20 square feet of basal area per acre and any amounts of clumped residuals should be treated.

3. However, from 30 to 80 good quality stems of beech and/or sugar maple may be left per acre in the cherry-maple forest type to ensure a component of these species in the future stands. Good formed oaks are desirable residuals too.

4. When possible, chainsaw fell the residuals during or after logging. Chainsaw felling is cheaper and provides a better residual stand appearance than chemical applications.

5. Chainsaw felling promotes stump sprouts. Cut low stumps to provide good low origin sprout attachment.

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Possible Alternatives to Clearcutting and Selection Harvesting Practices

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Abstract

The key to forest management begins with landowner objectives. Once these are known, foresters need a variety of silvicultural alternatives to begin stand management and gain landowner confidence. Possible alternatives and modifications are suggested for clearcutting and selection harvesting practices. These relate to improving esthetics in the instance of clearcutting and regenerating more intolerant species when selection cutting. Leaving residual trees, using longer cutting cycles, and applying the diameter-limit concept are some of the possibilities.

Introduction

There are a number of harvesting practices used to regenerate Appalachian hardwood stands. Clearcutting is the primary even-age harvesting practice, along with shelterwood and seed-tree methods. Single-tree and group selection are the recommended uneven-age harvesting methods. However, in practice, partial cuts such as diameter limits or improvement cuts are the primary "uneven-age" methods used by landowners (Perkey and Powell, this proceedings).

In many instances, neither clearcutting nor selection harvesting is acceptable to the landowner or the forester. Clearcutting is silviculturally acceptable and justified for regenerating desirable intolerant and some tolerant species. However, landowners and the general public are often opposed any even-age harvesting method that results in the removal of all of the canopy within a short time. This opposition relates primarily to esthetic values--the size and shape of clearcuts and the high visibility of dead and down wood (slash) and roads.

Partial cutting, such as single-tree selection, is far less objectionable to landowners and the public. However, usually partial cuts will not result in the development of high-value, fast-growing, shade-intolerant species in the overstory canopy, and foresters usually want to regenerate some intolerant species.

A key to improving esthetic values relates to the presence of slash and the amount of standing timber in the residual stand. Foresters must pay attention to stump, snag, and slash disposal. Slash reduced to a height of 3 feet or less will increase scenic quality. The use of chipping and similar techniques that remove slash from the site quickly also is important. In the Appalachians, the visual impact of slash is temporary; the decay of slash coupled with the development of regeneration effectively eliminates the adverse visual impact of dead and down material (slash) within a few years after logging (Vodak et al. 1985).

Where there are strong concerns related to the visual impact of standing timber in the stand after logging, it is recommended that a minimum residual basal area (RBA) of about 75 square feet per acre be maintained (Vodak et al. 1985). As more trees are removed and the RBA decreases, the presence of residual stems is not as important esthetically as how the dead and down wood is handled, lopped, or chipped. In this paper, I suggest alternative harvesting methods to make clearcutting and selection harvesting more acceptable to both the landowner, public, and the forester.

Alternatives to Clearcutting

Leave residual trees. Leave some trees in the residual stand for a long period. These trees can saplings, poles, and/or sawtimber-size trees or mixtures.

Those recently visiting the Fernow Experimental Forest near Parsons, WV, or the Monongahela National Forest could have seen a "deferment" cutting practice. This practice is sometimes used in Europe for certain forest types (primarily oak-beech) to improve esthetic values after clearcutting (Kostler 1956; Troup 1966). The deferment practice resembles a seed-tree cut except that the residual sawtimber-size trees are not cut when the regeneration becomes established. Instead, the removal of these residual trees usually is deferred until the regenerated stand is mature. The RBA's are about 20 square feet per acre in 12 to 15 sawtimber-size trees. All other trees 2 inches dbh and larger are cut.

A similar practice called "insurance silviculture" was applied to Allegheny hardwood cherry-maple stands by Bennett, Armstrong (1981). However, their main objective was to address regeneration problems associated with deer. Between 20 and 40 pole- and small sawtimber-size trees 8 to 12 inches dbh, (or a basal area of 14 to 18 square feet per acre) were left. All other trees larger than 0.5-inch dbh were cut. Primary insurance species were sugar and red maple.

Marquis et al. (1984) reported a similar practice for cherry-maple stands, leaving only about 10 square feet per acre in large stems of sapling-pole size (tolerant species). All other trees 2 inches dbh and larger, including culls and nonmerchantable trees, are removed. One of the reasons for leaving these poles is to provide a future seed source to minimize the

development of a black cherry monoculture that commonly occurs (without deer) following clearcutting of black cherry stands.

Another approach for leaving more residual trees in second-growth mature hardwood stands is the use of crop-tree selection and release techniques. Select the best 20 to 50 crop trees per acre (depending on species) to grow for another 10 to 30 years, i.e. mark trees to leave rather than cut. Cut all other dominant, codominant, and intermediate trees that touch the crown of the selected crop trees. Adjacent crop trees with touching crowns would not be cut. Regardless, regeneration will develop for many years without major interference from the residual overstory canopy. Thus, apply crop tree release cultural practices to mature stands using techniques similar to those for immature stands. Think about it.

The following are recommendations for leaving residual trees:

1. Leave long-lived tree species that will live for another 80 to 120 years. Most second-growth trees are about 80 years old. Species such as red oak, white oak, sugar maple, beech, and possibly yellow-poplar are good choices.

2. Leave low-risk, sound trees that are not rotten or show evidence of decay. A few den trees or potential den trees, i.e., those with dead limbs that may develop cavities, should remain in the stand. This would include species such as basswood, beech, or white ash.

3. Leave a RBA of 20 to 30 square feet per acre in sawtimber-size trees. Cut all other sawtimber- and pole-size trees. Note that in many instances, cutting the residual sapling stems may be questionable, at least from a silvicultural standpoint (B. Brenneman, this proceedings).

4. Or leave a RBA of 10 square feet in large trees of sapling-pole size. Cut all remaining trees 2 inches dbh and larger. When leaving large saplings or pole-size trees in the residual stand, favor the more tolerant species such as maples, beech, and oaks. Favor trees with the best crowns and avoid trees with existing epicormic branches.

5. Consider cutting all pole and sawtimber stems larger than 6 to 8 inches dbh and leave all saplings and small poles. Logging will destroy many of the small stems but an overstory will be present and some intolerant regeneration will develop. We have seen where all trees above 8 inches dbh were cut and intolerant species developed as a major portion of the next stand (Smith and Lamson 1977).

6. Consider the crop tree release approach in mature stands. Mark trees to leave in the residual stand. Select the best 20 to 50 crop trees per acre to leave for another 10 to 30 years. Use the crown touching release technique and cut all dominant, codominant, and intermediate crown class trees touching the crop tree. If the advanced understory is desirable, leave it. If the advanced understory is undesirable, consider recommendations by Brenneman (this proceedings).

Logging damage. A major concern is logging damage to residual trees, primarily exposed sapwood at the base of the butt log. If good-quality timber or potential trees are left for a long period, logging damage can be considerable. When selecting good-quality sawtimber- or pole-size trees for the residual stand, try to minimize logging damage to these trees. Some ways to do this are:

1. Winch-skid shorter tree lengths (logging cost increases).

2. Clearly mark leave trees (paint) on all sides so marking is visible to the logger.

3. Use directional felling techniques to avoid these special trees.

4. Since trees are easily damaged "barked" during the spring, limit logging during this period or try to protect these residual trees during winching, skidding, and felling.

5. Quality dominant-codominant sawtimber trees (20 square feet per acre) or sapling-poles (10 square feet per acre) are normally left for potential timber products. Instead, consider leaving some poor-quality sawtimber or sapling-pole timber that will live. This will eliminate loss in quality due to exposure, windthrow, logging damage, and epicormic branching. Esthetic concerns will be satisfied, too. Many of these poor trees could be removed (felled or herbicided) before or during the first commercial thinning. I realize this is not a normal recommendation. Some would call this practice high grading; however, this is suggested as a way to establish a new stand without clearcutting all of the trees. Leaving poor-quality trees as a sparse overstory and removing all other pole and sawtimber trees has been suggested by nonforestry groups. The idea has some potential especially where the poor trees are removed during early stand cultural practices or at the first commercial thinning.

Practice more shelterwood. Another alternative to clearcutting is to use more shelterwood-type practices so that the the stand always has an overstory canopy that will improve some of the unattractive appearances associated with clearcutting. Usually there are two to three shelterwood cuts. In most cases, logging and market economics limit the number of removal cuts. When economically feasible, remove the overstory stand in three cuts within about a 20-year period. For the first cut, remove 40 to 60 percent of the volume (basal area) in sawtimber- and pole-size trees. If more volume is removed during the first cut, the amount of damage to the residual stand following a second or third cutting period should be reduced.

1. Consider a three-cut shelterwood. On good oak sites try a 50-30-20 percent volume removal within a 20-year period. The change in stand conditions will be more gradual, and though some regeneration will be lost with each removal cut, intolerant species will be regenerated. If this is not economically feasible, consider two cuts within a 10- to 15-year period. Applying a three-cut shelterwood on a lower site (oak SI 60 or less) may not be economical.

2. Consider leaving the overstory after the second cut. If this is done then a 60-30-10 shelterwood removal plan might be used where the 10 percent is left in the stand to develop. However, some of these trees could be removed during a commercial thinning.

3. A possible modification of the three-cut shelterwood is where only two merchantable cuts are applied. Remove the best trees and species during the first cut (assuming none are needed to provide seed). For the second cut, remove the better trees and species that are present. The next potential cut would then include the poorest quality trees and least desirable species. For this last removal cut, the best option may be to fell these trees, or use chemicals, or wait until the first commercial thinning.

4. Do not consider a removal cut until after the new regeneration is at least 10 to 15 feet tall. The unattractive appearance associated with clearcutting is reduced and these stands would contain overstory trees of at least sapling size. Watch the regeneration for signs of poor quality (Smith 1986). If the young trees develop unhealthy foliage, bend toward the light, or fail to maintain a good rate of height growth, remove some or all of the overstory. Damage will occur in the new stand with each removal cut. This can be reduced by careful logging and the use of directional felling techniques.

5. Consider an irregular shelterwood (Smith 1986). This concept has its greatest use in mixed hardwood stands where one of the valuable species has a much longer rotation age than the other major species. The shelterwood removal "ignores" the long-rotation species. As the stand continues to develop, these long-rotation species are removed eventually.

6. If regeneration does not become established after this first cut, consider planting. However, in the Appalachians, desirable regeneration usually becomes established at the first cut when 40 to 60 percent of the volume is removed. Though high deer populations can create major regeneration development problems.

There is the potential to regenerate thousands of seedlings and sprouts on forest sites but as these stands mature, only a few hundred trees per acre are needed for success. Foresters must alter or modify traditional clearcutting techniques and develop ways of establishing adequate but not an overabundance of intolerant regeneration. When this is done, there will be a risk to foresters who wish to regenerate the maximum amount of desirable intolerant species, though public criticism should be reduced in most cases.

Alternatives to Selection

Because partial harvesting cuts usually are accepted by the public, foresters need to consider partial cutting techniques that still satisfy silvicultural objectives. Foresters often remark that the selection practice is difficult to apply. Although single-tree selection is widely recommended, this method is rarely used. In the past, most of the so called selection practices were improvement cuts where the best trees were left for the future. Little cutting was done in the overstory canopy and no special considerations were given for establishing regeneration or developing stems from one diameter class to the next (stand structure). This improvement approach is certainly valid, especially where stands have not been managed previously. Improvement cuts are useful for one or possibly two selection-cutting cycles, but eventually there must be ways to consistently select good trees for cutting, establishing regeneration, and developing stand structure (Smith and Lamson 1982).

With single-tree selection and other partial cuts, tolerant species regenerate and develop. Intolerant species have little opportunity to develop because the understory usually is shaded all of the time. There are only a few tolerant species that become established and through time develop into the overstory canopy. Often, these species are slower growing and less valuable to the resource user than the intolerant species. Also, compared to the maples, beech is one of the few commercial tolerant hardwood species that provide food for wildlife.

Use longer cutting cycles. One modification to single-tree selection is to the use of longer cutting cycles. Typically, cutting periods range from 10 to 20 years depending on site quality.

> Consider 20- to 40-year cutting cycles. Because more volume can be cut during each cutting period, larger openings will occur in the overstory canopy. Some intolerant species will be established and develop. For some sites and stands, cut volumes per acre could easily approach 7,000 to 8,000 board feet (International 1/4-inch). The major disadvantages of longer cutting cycles are salvaging trees damaged during logging and not being able to harvest dying trees.

Manage some poletimber trees. Markets are a key to application of partial cutting practices such as single-tree selection. Where markets are not available for poletimber products, landowners should consider at least removing some cull trees (leave a few for wildlife) and undesirable trees. Fell these trees during logging. It makes little sense to continue to concentrate growth on poor trees until these trees become large enough to cut as small sawlogs (Smith and Miller 1987).

Apply financial-maturity cutting concept. A financial-maturity cut is an alternative to single-tree selection. In the field, this practice is applied as a flexible diameter limit based on species, site index, and desired rate of return (Trimble et al. 1974). A partial-type cutting appearance is achieved that based on our experiences is acceptable to the public. Using this concept:

1. Individual tree financial maturity is combined with an improvement cut to achieve silvicultural goals for sawtimber stands.

2. Trees that exceed a selected rate of return due to rapid growth or quality are left in the stand to grow.

3. Trees earning less than a selected rate of return are financially mature and can be cut.

Current tree dbh and anticipated growth determine the potential real rate of return. Diameters that correspond to financial maturity for each species are determined before the stand is marked (Table 1). In the field, species, dbh, and tree characteristics determine whether an individual tree is cut or retained.

To use Table 1, select a rate of return that is based on site and stand conditions. If a 3-percent rate is used on oak site index 70, all yellow-poplar trees 21.0 inches dbh and larger are eligible for cutting. Similarly, all black cherry 25.0 inches dbh and larger can be removed.

Another portion of this financial-maturity concept involves a silvicultural or improvement cut according to the following guidelines:

1. Mark sawtimber size trees above 11.0 inches dbh.

2. Fell culls and trees with a butt log grade 4 or 5.

3. Cut trees with significant rot in the butt log (40 percent or more).

4. Mark low-vigor trees.

5. Remove short-lived species that you want to discourage, regardless of dbh. Examples would include black locust, sassafras, Fraser magnolia, and butternut.

6. Cut all high-risk sawtimber trees.

Table 1.--Financial-maturity cutting diameters for Appalachian hardwood species, by red oak site index and selected rate of return

Species	2%			3%			4%			5%			6%		
	80	70	60	80	70	60	80	70	60	80	70	60	80	70	60
	Minimum Cutting Diameter (2-inch dbh)														
Yellow-poplar	26	26	24	24	22	22	20	18	18	20	18	18	18	18	18
Beech	24	22	22	22	20	20	20	18	18	20	18	18	18	18	18
Black cherry	32	30	30	28	26	24	22	20	18	20	20	18	18	18	18
Red maple	32	30	30	28	26	24	22	22	18	20	20	18	18	18	18
White ash	30	28	28	26	24	24	22	20	18	20	20	18	18	18	18
Sugar maple	32	32	30	28	28	24	22	22	18	20	20	18	18	18	18
Red oak	26	26	24	24	24	22	22	22	20	22	20	20	20	18	18
White oak	24	22	20	22	20	20	20	18	18	20	18	18	18	18	18
Chestnut oak	24	24	22	22	22	20	20	18	18	20	18	18	18	18	18
Other (long-lived)	26	26	24	24	24	22	20	20	18	20	20	18	18	18	18

Consider a low minimum cutting diameter for any undesirable species you want to eliminate from the stand. For example, cutting unwanted species consistently at 6 inches dbh eventually eliminates this seed source and effectively controls stump sprouting.

Guidelines on the appropriate RBA are available for various site indexes and rates of return (Trimble et al. 1974). For example, on oak site index 80, the recommended RBA is between 70 and 85 square feet per acre in trees over 11.0 inches dbh. If the stands have not been managed (cut), managed

recently, then the RBA after the first cut should be toward the higher level. A 10-year cutting cycle is used for good site: 15 years is suggested for stands on oak site index 60 areas.

The following are some of the ways in which the financial-maturity concept can be applied or modified.

1. Minimum cutting diameters can be adjusted for more applicability based on experience. For example, undesirable sawtimber species could have a lower minimum cutting diameter, such as 12 to 14 inches dbh. Beech, sourwood, blackgum, aspen, Fraser magnolia, sassafras, and possibly red maple, are a few of these species.

2. To manage quality sawtimber trees, use at least 16 and preferably 18 inches dbh as the minimum cutting diameter. A 16-inch-dbh tree is the minimum size necessary for the butt log to qualify as a potential grade 1 sawlog (USDA Forest Service log grades).

3. Remove undesirable species or poor-quality trees below the minimum cutting diameter. Consider this for all sawtimber trees and, where possible, poletimber trees. If these trees are marked, many can be felled during logging and left in the woods.

4. Fell cull trees. Our experience indicates that girdling or using chemicals does not consistently kill trees. Leave a few desirable cull trees per acre for wildlife dens and nesting cavities. Fell the rest.

Use diameter-limit? Another alternative to single-tree selection is the commonly practiced diameter-limit cut. In fact, diameter limit may be the partial-cutting method practiced most often in eastern hardwood stands. Based on use, landowners are sending a message to foresters that is loud and clear: "For partial cutting, our choice is diameter limit. Foresters give us better ways to do diameter limits that are more acceptable to you."

Diameter-limit cutting is the periodic removal of trees above a minimum stump diameter or dbh. Normally, there is no cutting or cultural practice applied in the pole or sawtimber stand below the minimum cutting diameter. A 12- to 14-inch stump diameter-limit cut is commonly used because trees of in this diameter class generally are large enough to provide a log that can be sold at the mill. Also, logging and milling costs are lowered when the minimum diameter is high enough to eliminate cutting or winching of small, low-value trees. In general, diameter-limit cutting is not "bad" when the minimum cutting diameter is high (18 to 20 inches dbh) or low (6 to 8 inches dbh).

With diameter-limit cutting there is no means of regulating the periodic volume removed. Both good and poor trees below the diameter limit continue to grow and tolerant species often dominate future stands. Cull trees below the diameter limit are not removed; sometimes, cull trees above the minimum diameter limit are not removed either. Initially, the faster growing trees are cut, and dying or damaged trees below the minimum diameter are not cut. Tree species that tend to produce epicormic branches might suffer degrade by diameter-limit cutting. Trees with small crowns that have been in the intermediate and lower crown classes are especially susceptible. Also, the development of trees below the minimum cutting diameter in the sapling-pole-sawtimber classes is left to chance. However, a diameter-limit cut is easy to apply in the woods. Landowners often tell loggers the minimum cutting diameter and no tree marking is done.

In general, foresters do not recommend diameter-limit cutting and commonly consider this practice as a type of high-grading--taking the best and leaving the worst. They contend that after a few cuts, high-quality stands can be reduced to low-quality stands.

I believe that with a few modifications, diameter-limit cutting is an acceptable method when a high minimum cutting diameter is used (Smith, et al.). Often, second-growth hardwood stands 80 years or older contain many stems 18 inches dbh or larger. The following are possible modifications to consider for the diameter-limit concept.

1. Raise the minimum cutting diameter. Use high minimum cutting diameters, at least 16 and preferably 18 inches dbh. Larger sawtimber-size trees have a better chance to produce grade 1 butt logs. Log grade increase is normally based on a diameter increase. The selling price for grade 1 sawlogs is significantly higher than for grade 2, 3, or lower quality logs. As a result, butt logs, where the minimum cutting dbh is less than 16 inches, have little opportunity for this "several fold" increase in value because most are cut before they become eligible for grade 1. For a 16-inch-dib sugar maple sawlog, grades 1, 2, and 3 correspond to a value ratio of 7:4:1, respectively. Thus, the grade 1 log is worth 7 times more than a grade 3 while grade 2 is worth 4 times more than grade 3. Veneer compared to sawlogs would be higher, too.

2. For each periodic cut do not remove more volume than the average periodic growth. Thus, for a 20-year cutting cycle in mature stands growing 300 board feet per year, about 6,000 board feet per acre could be cut without concern for overcutting.

3. Apply cultural practices below the minimum cutting diameter. This includes removing culls and undesirable trees and species of sawtimber size (leave a few cull trees per acre that are desirable to wildlife). Also, consider removing undesirable species in the poletimber stand. These species will not improve with age and are using space, moisture, and nutrients that other more desirable species could use.

4. Use "differential diameter limits" (Smith 1986). In this practice, different diameter limits are established for each species (like flexible diameter limits). High diameter limits could be set for more valuable species and low diameter limits for less valuable species.

Alternatives to Group Selection.

With group selection, where small openings are created in the stand primarily to regenerate some intolerant species. In practice, most of the group selection cuts are patch clearcuts because area control is used to regulate the periodic cut (Smith 1980). This is even-age management. However, the key point is that small clearcuts usually are acceptable to the public.

Openings are cut where stand reproduction is desired, usually in mature or overmature timber. And the openings are circular to rectangular. When possible, an improvement cut is applied (low thinning) between the openings.

Use small openings. There is confusion in terminology when discussing group selection versus patch clearcuts. Replace these terms with "small openings". Then define the characteristics of "your" small openings. The purpose of this cutting practice is to periodically establish small openings in a forest stand. How these small openings are established in the woods, using area or volume, is not that important at this time. The following are considerations concerning the use of small openings.

1. The total border area of many small openings can be several times that of one clearcut that covers the same acreage.

2. Some border trees (such as black cherry, basswood, and oaks) tend to produce epicormic branches, which can result in log degrade.

3. Small openings provide favorable habitat for many species of wildlife; but, if plentiful, deer can destroy or damage much of the reproduction by constant browsing.

4. If there are grapevines on better sites, the vines may spread rapidly in the small openings and reduce tree quality or even kill trees.

5. In Appalachian hardwood stands on steep slopes, it can be difficult to maintain regeneration in small clearcut openings. When mature trees are felled and logged periodically, trees often damage or destroy a considerable number of saplings and pole-size trees in previously cut openings.

Group selection may be effective on small forest ownerships or on large properties. However, foresters have not developed on-the-ground techniques to implement this practice, and, in general, they have not promoted group selection.

For the establishment and development of intolerant regeneration, openings should be at least 1/2-acre in size (Smith 1981); up to about 2 acres may be a reasonable compromise (Burns 1983). You also may want to consider the following:

1. Vary the size of the openings within a given cutting period; that is, allow the existing stand conditions (up to about 2 acres) to determine the size of individual openings.

2. Use longer than normal cutting cycles, perhaps 20 to 40 years between entry periods (maximum of four to five entry periods per "rotation"). There is less variation in the stands due to different age classes compared to the shorter cutting cycles. Longer cutting intervals allow the stand to develop from regeneration to sapling and perhaps poletimber size before the next entry period. Logging damage to these established stands should be reduced since loggers can see the trees and are more likely to use directional felling or tree winching concepts.

3. When longer cutting periods are used, an improvement cut throughout the stand might be possible at each cutting period.

4. Use strip cutting along with a management plan to initially predesignate cut areas for each cutting cycle on a map (Smith and Wendel 1976). During the first "rotation," overmature and immature trees will not be cut or will be cut too soon. But long-term management should be better from a fixed strip compared to the random selection of openings wherever they can be found. Also, trees can be marked between the strips.

Summary

Alternatives or modifications have been suggested for the clearcutting and single-tree selection practices. Foresters need to seek out and be more attentive to the interest and objectives of landowners. In many instances, if the forester invests time in understanding the landowners' objectives and

explaining alternatives, good forestry can be practiced and major silvicultural objectives can be achieved. With a little ingenuity, foresters may be able to satisfy more silvicultural objectives than they initially realize. Once the landowner's objectives are known, the forester can begin to suggest compromises to satisfy both objectives. There is an urgent need to help landowners increase their knowledge and awareness of necessary tradeoffs.

In general, the greatest concern associated with clearcutting and selection practices is the amount of slash present in the residual stand. This concern increases as residual stand densities fall below 75 square feet per acre. To reduce or eliminate public opposition, foresters managing public lands need to do a better job of disposing slash and providing information on postharvest stand development. Similarly, industrial foresters may find that the use of techniques to minimize slash is an inexpensive way to improve the public's image of forestry and their company (Vodak et al. 1985).

Foresters have to modify their traditional ways of thinking and compromise is necessary in order for foresters to begin or to continue to manage many Appalachian hardwood stands. A silvicultural practice may not be the forester's "first choice" biologically, but the practice is still acceptable to the landowner-forester and as such serves as the first step in managing a forest stand.

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APPENDIX

Common and Scientific Names of Tree Species

Hardwoods

Alder	Alnus Mill. sp.
Alder, European	Alnus glutinosa (L.) Gaertn.
Apple	Malus sp.
Apple, crab	Malus coronaria (L.) Mill.
Ash, white	Fraxinus americana L.
Ash, green	Fraxinus pennsylvanica Marsh.
Aspen, bigtooth	Populus grandidentata Michx.
Aspen, quaking	Populus tremuloides Michx.
Basswood, American	Tilia americana L.
Basswood, white	Tilia heterophylla Vent.
Beech, American	Fagus grandifolia Ehrh.
Birch, gray	Betula populifolia Marsh.
Birch, paper	Betula papyrifera Marsh.
Birch, river	Betula nigra L.
Birch, sweet	Betula lenta L.
Birch, yellow	Betula alleghaniensis Britton
Blackgum; Tupelogum	Nyssa sylvatica Marsh.
Boxelder	Acer negundo L.
Buckeye, Ohio	Aesculus glabra Willd.
Buckeye, yellow	Aesculus octandra Marsh.
Catalpa, northern	Catalpa speciosa Warder ex Engelm.
Cherry, black	Prunus serotina Ehrh.
Cherry, European	Prunus mohaleh L.
Cherry, fire	Prunus pensylvanica L. f.
Cherry, pin	Prunus pensylvanica L. f.
Cherry, sweet	Prunus avium (L.) L.
Chestnut, American	Castanea dentata (Marsh.) Borkh.
Chokecherry	Prunus virginiana L.
Coffeetree, Kentucky	Gymnocladus dioicus (L.) K. Koch
Cottonwood, eastern	Populus deltoides Bartr. ex Marsh.
Cucumbertree	Magnolia acuminata
Dogwood, flowering	Cornus florida L.
Dogwood, panicled	Cornus racemosa Lam.
Elm, American	Ulmus americana L.
Elm, slippery	Ulmus rubra Muhl.
Hackberry	Celtis occidentalis L.
Hawthorn	Crataegus L. sp.
Hazelnut	Corylus L. sp.
Hickory, bitternut	Carya cordiformis (Wangenh.) K. Koch.
Hickory, mockernut	Carya tomentosa Nutt.
Hickory, pecan	Carya illinoensis (Wangenh.) K. Koch.
Hickory, pignut	Carya glabra (Mill.) Sweet.
Hickory, shagbark	Carya ovata (Mill.) K. Koch.
Holly, American	Ilex opaca Ait.

Honeylocust	Gleditsia triacanthos L.
Hornbeam, American	Carpinus caroliniana Watt.
Hophornbeam, eastern	Ostrya virginia (Mill.) K. Koch.
Locust, black	Robinia pseudoacacia L.
Magnolia, Fraser	Magnolia fraseri Walt.
Maple, mountain	Acer spicatum Lam.
Maple, Norway	Acer platanoides L.
Maple, red	Acer rubrum L.
Maple, silver	Acer saccharinum L.
Maple, striped	Acer pensylvanicum L.
Maple, sugar	Acer saccharum Marsh.
Mountain ash, American	Sorbus americana Marsh.
Mulberry, red	Morus rubra L.
Oak, black	Quercus velutina Lam.
Oak, blackjack	Quercus marilandica Muenchh.
Oak, chestnut	Quercus prinus L.
Oak, northern red	Quercus rubra L.
Oak, pin	Quercus palustris Muenchh.
Oak, post	Quercus stellata Wangenh.
Oak, scarlet	Quercus coccinea Muenchh.
Oak, southern red	Quercus falcata Michx.
Oak, shingle	Quercus imbricaria Michx.
Oak, water	Quercus nigra L.
Oak, white	Quercus alba L.
Pawpaw	Asimina triloba (L.) Dunal
Pear	Pyrus communis L.
Persimmon	Diospyros virginiana L.
Poplar, Lombardy	Populus nigra var. italica Muenchh.
Poplar, silver	Populus alba L.
Redbud	Cercis canadensis L.
Sassafras	Sassafras albidum (Nutt.) Nees.
Serviceberry	Amelanchier arborea (Michx. f.) Fern
Sourwood	Oxydendrum arboreum (L.) DC.
Sumac	Rhus L. sp.
Sweetgum	Liquidambar styraciflua L.
Sycamore, American	Platanus occidentalis L.
Walnut, black	Juglans nigra L.
Walnut, butternut	Juglans cinerea L.
Willow	Salix L. sp.
Willow, black	Salix nigra Marsh
Witch-hazel	Hammamelis virginiana L.
Yellow-poplar	Liriodendron tulipifera L.

Conifers

Baldcypress	Taxodium distichum (L.) Rich.
Fir, balsam	Abies balsamea (L.) Mill.
Fir, Fraser	Abies fraseri (Pursh) Poir
Hemlock, eastern	Tsuga canadensis (L.) Carr.
Juniper, common	Juniper communis L.
Larch	Larix laricina (DuRoi) K. Koch

Pine, eastern white	Pinus strobus L.
Pine, loblolly	Pinus taeda L.
Pine, pitch	Pinus rigida Mill.
Pine, shortleaf	Pinus echinata Mill.
Pine, table mountain	Pinus pungens Lamb.
Pine, Virginia	Pinus visginia Mill.
Redcedar, eastern; juniper	Juniperus virginia L.
Spruce, red	Picea rubens Sarg.

Other Plants

Alfalfa	Medicogo sativa L.
Autumn-olive	Elaeagnus umbellata Thunb.
Blackberries	Rubus sp.
Bittersweet, nightshade	Solanum dulcamara L.
Bittersweet, oriental	Celastrus orbiculatus Thunb.
Blackberry, Allegheny	Rubus allegheniensis Porter
Blackberry, European	Rubus almifolius
Blueberries	Vaccinium sp.
Clover	Trifolium sp.
Cohosh, blue	Caulophyllum thalictroides (L.) Michaux
Elderberry	Sambucus canadensis L.
Fern, bracken	Pteridium aquilinum L.
Fern, hayscented	Dennstaedtia punctilobula (Michx.) Moore
Fern, interrupted	Osmunda claytoniana L.
Fern, New York	Thelypteris noveboracensis L.
Fern, sensitive	Onoclea sensibilis L.
Fern, wood	Dryopteris spinulosa (O.F. Muell.) Watt
Gallberries	Ilex sp.
Grape sp.	Vitis sp.
Grape, riverbank	Vitis riparia Michx.
Grape, silverleaf	Vitis aestivalis var argentifolia Munson
Grape, summer	Vitis aestivalis Michx.
Grass, Kentucky blue	Poa pratensis L.
Grass, poverty oat	Danthonia spicata (L.) Beauv.
Grass, short husk	Brachyelytrum erectum Schreb.
Grass, wild oat	Danthonia compressa Aust.
Greenbriers	Smilax rotundifolia L.
Honeysuckle	Rhododendron atlanticum (Ashe) Rphd.
Honeysuckle, azalea	Rhododendron roseum (Loisel.) Rehd.
Honeysuckle, Japanese	Lonicera japanica Thunb.
Kudza	Pueraria lobata (Willd.) Ohwi
Laurel, mountain	Kalmia latifolia L.
Laurel, sheep	Kalmia angustifolia L.
Raspberry	Rubus sp.
Raspberry, black	Rubus occidentalis L.
Rhododendron	Rhododendron maximum L.
Rose, multiflora	Rosa multiflora Thunb.
Rubus sp.	Rubus sp.
Sarasparilla	Aralia nudicaulis L.
Silverbell, Carolina	Halesia carolina L.

Soybeans	Glycine max (L.) Merr.
Spicebush	Lindera benzoin (L.) Blume
Sweetfern	Comptonia peregrina (L.) Coult.
Vetch	Vicia sp.
Viburnum	Viburnum sp.
Vine, Dutchman's-pipe	Aristolochia durior Hill

Wildlife and Nongame

Chipmunk, eastern	Tamias striatus
Deer, black-tailed	Odocoileus hemionus
Deer, mule	Odocoileus hemionus
Deer, white-tailed	Odocoileus virginianus
Elk	Cervus elaphus
Jay, blue	Cyanocitta cristata
Mountain lion	Felis concolor
Mouse, deer	Peromyscus maniculatus
Mouse, white-footed	Peromyscus leucopus
Squirrel, fox	Sciurus niger
Squirrel, gray	Sciurus carolinensis
Turkey, wild	Meleagris gallopavo
Turtle, eastern box	Terrapene carolina
Vole, red-backed	Clethrionomys gapperi